NOTES

ON

LAYING, REPAIRING, OPERATING, AND TESTING SUBMARINE CABLES

U. S. SIGNAL CORPS
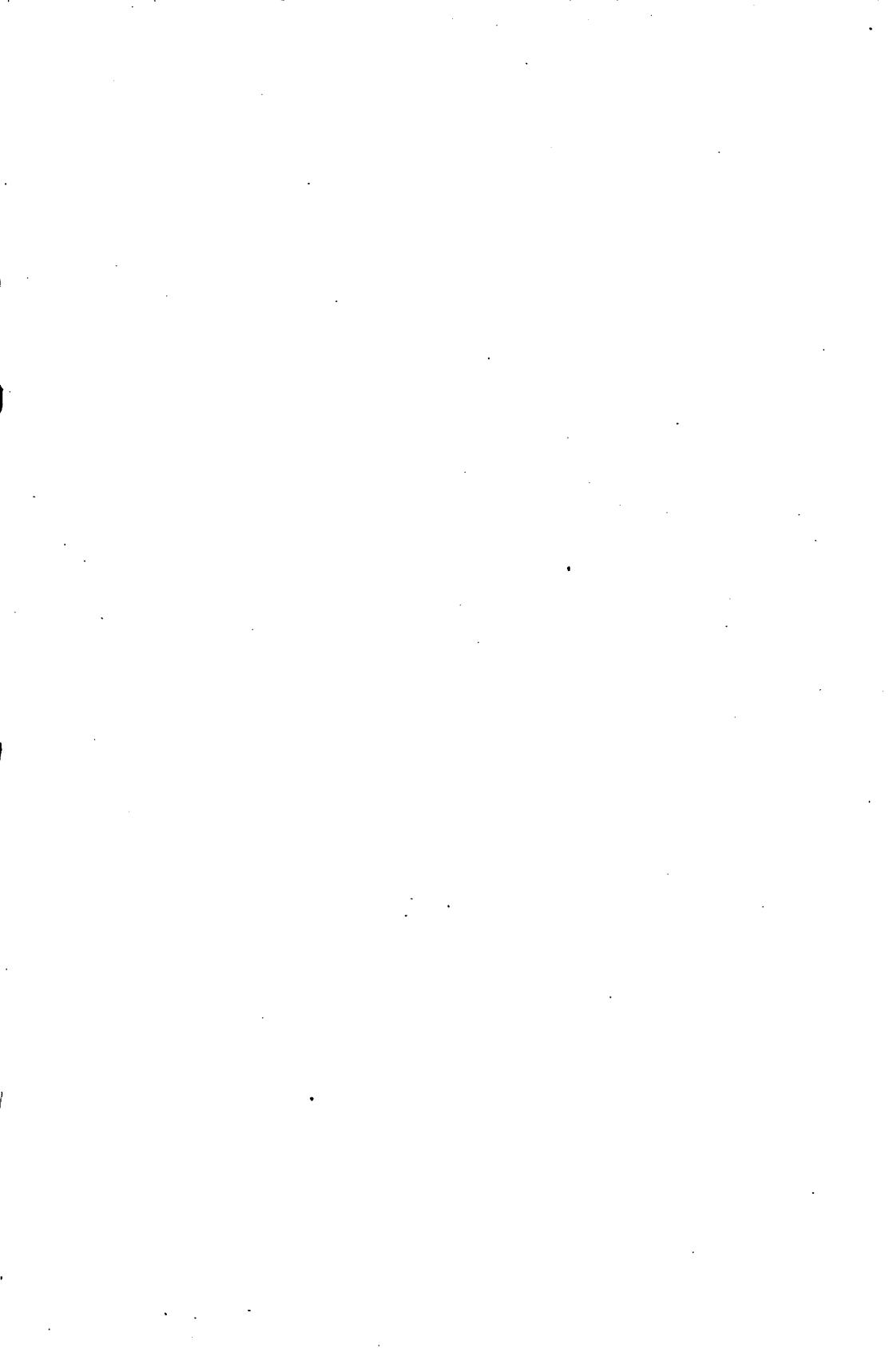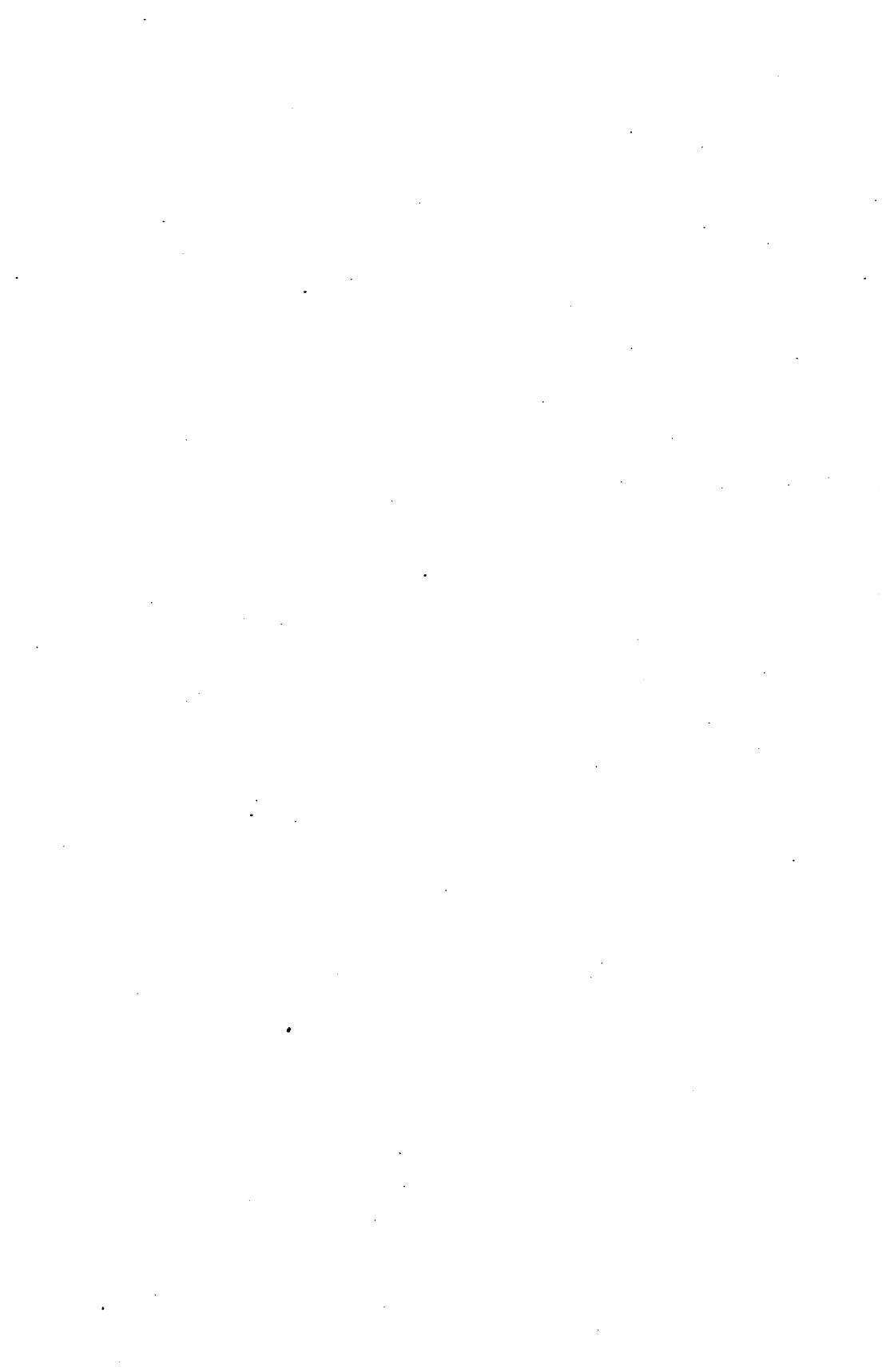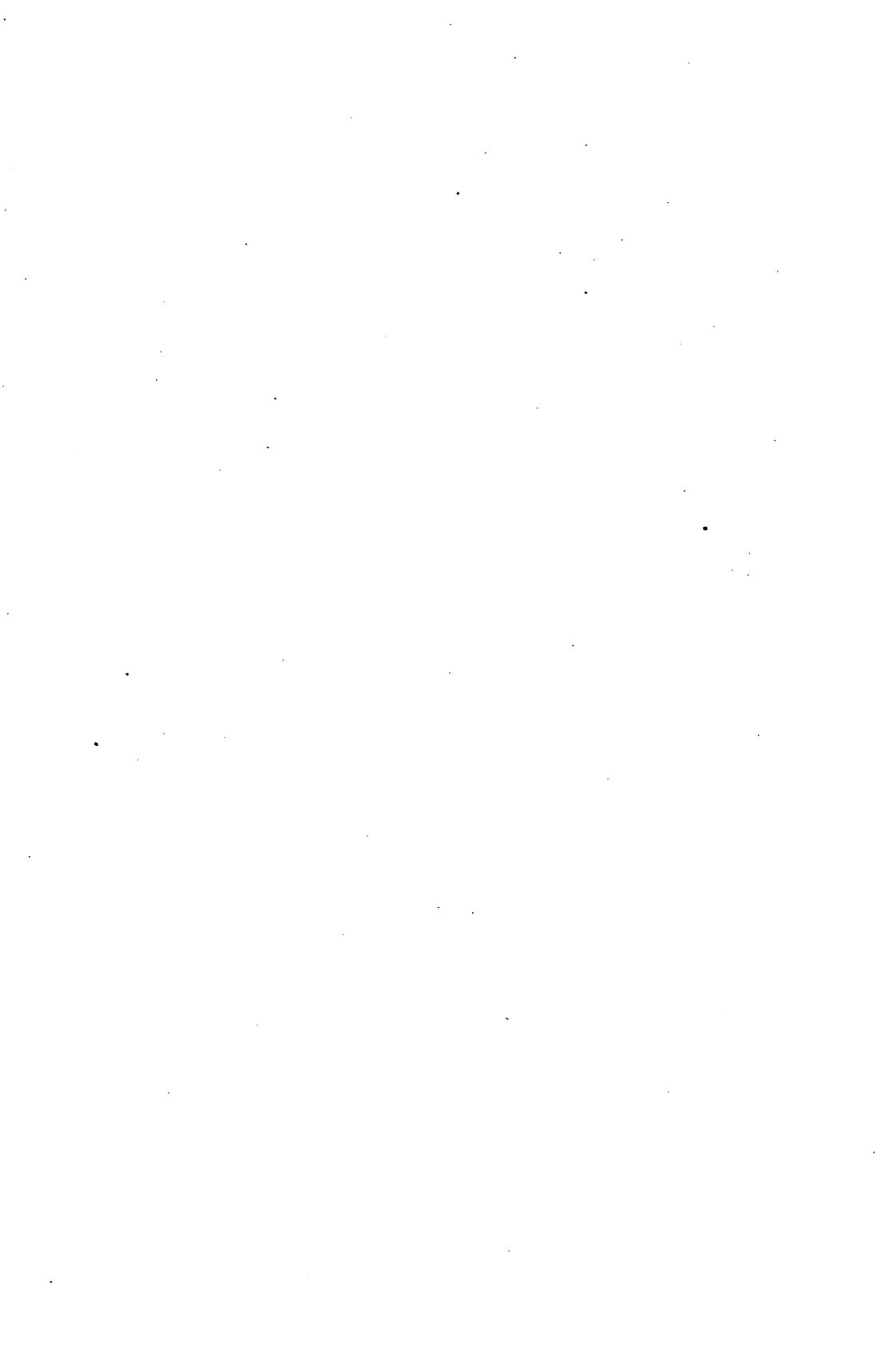
1902

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ON

LAYING, REPAIRING, OPERATING, AND TESTING SUBMARINE CABLES.

U. S. SIGNAL *Service* CORPS.

Prepared under the direction of

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WITH SUPPLEMENTARY CHAPTER ON FACTORY TESTING

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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1902.
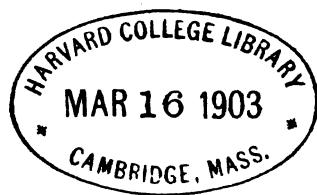
WAR DEPARTMENT,

Document No. 172.

Office of the Chief Signal Officer.

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SUBMARINE CABLE WORKING.

CONSTRUCTION, LAYING, REPAIRING.

The Signal Corps has of late years had much to do with this branch of telegraph engineering. The special technical character of the work is such that if it were attempted to describe cable laying from a cable ship it would be impracticable to give much idea of it in the brief way necessary here.

Two works exist which enter quite fully into the whole subject. These are *Submarine Cable Laying and Repairing*, by H. D. Wilkinson. The other is *Submarine Telegraphs*, by Charles Bright. A just idea of the many practical questions involved may be obtained only by actual experience on a cable ship. It is proposed to enter only briefly into some of the questions concerning the cable, its repair,
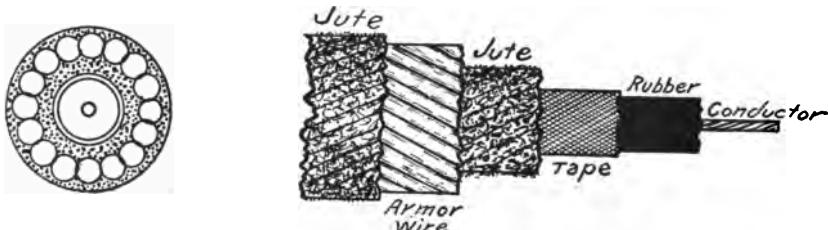
FIG. 1.

expedients for laying short pieces in shallow water, cable stations, and instruments and elementary testing which are liable to come up for practical solution.

The cables so far laid by the Signal Corps are rubber-insulated ones. A detail view of the typical form is given in fig. 1. This is the actual size of some of the cables laid in Philippine waters. The conductor at the center consists of 7-strand tinned copper wire, the wires in the strand being usually No. 21 or No. 24 Brown & Sharpe gauge, having resistances respectively of about 10 and 20 ohms per mile.

Around this is a layer, one sixty-fourth inch thick, of pure rubber, then a vulcanized rubber composition to a diameter of nine thirty-seconds inch. This is then covered with a layer of tape spirally put on. Outside of this two layers of tanned or tarred jute are laid on with the spirals in opposite directions. The galvanized-steel wire armor comes next. Outside this two more layers of jute are put on

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and served with hot asphalt compound. A final coating of lime or soapstone, to prevent the coils from sticking together, completes the cable. When the cable is in shallow water and subject to abrasion from wave action, another armor of galvanized-steel wires and outer coatings of jute is put on. This is called "shore end."

Multiple cables are made up with the india-rubber cores, as they are called, laid up closely together, and the armor wires and jute serving outside of all. The finished cable is coiled in circular tanks in the factory or ship. Cable should be kept submerged as much as possible, as it deteriorates far less rapidly when under water. It is especially needful to protect it from heat. Exposure to weather (sunlight, wind, or rain) causes very rapid deterioration.

For descriptions of cable-ship machinery and the operations of laying from the ship, reference is made to the works cited at the beginning.

However, as the Signal Corps is sometimes called upon to lay short cables in shallow waters by improvised means, an account of how it was done in Laguna de Bay, near Manila, P. I., may prove useful. The cable was coiled in a large "casco," or lighter, the coil being oblong (about 24 by 16 feet). Starting on the outside, it was coiled snugly inward to a diameter of about 4 feet, the man guiding it going around in a left-handed direction, the helpers squatted around keeping the coils closed in tightly together as the cable came down from above. A wooden "cone" was erected in the center to the height the pile was to reach, the edges and corners being well rounded off to prevent the cable catching as it paid out. In coiling inward the cable coils are carried up snugly against the core, and then the cable is carried radially across the lower layer ("flake," it is called) and another flake begun at the outer edge. If much cable is to be put on, narrow strips of wood (called "feathers") are laid along the piece of cable carried straight across. Close and careful coiling, especially in the lower flakes, is necessary.

Sheaves are lashed in proper places to carry the cable up, first over the center of the cone and then aft. Near the stern the cable passed under a horizontal roller, or "fair lead," and means were provided to press a timber against the cable here to pinch it and put on the necessary friction to prevent its paying out too rapidly. The necessary testing apparatus was installed, and the casco towed by one of the gunboats used on the lake. The end of the cable was carried ashore in two small boats, one buoying it between the casco and the boat nearest shore.

The end ashore having been properly trenched and anchored, paying out was begun. Several helpers were on the cable coils, handing the cable up as it started to rise and looking out that no kinks went up. An average speed of 2½ miles an hour was attained, the water being not over 40 or 50 feet deep. When the end was landed the cable was

trenched about 3 feet deep, down to low water. Above high water a short cross trench was dug, a heavy log was buried therein, and a chain lashed to it and the cable. This constituted a "sand anchor" to prevent the end of the cable from being pulled out to sea. The best way to electrically secure the land end of the cable is to run it into the office and connect the conductor directly with the office switch board. The next best is to splice the submarine cable to lead-covered underground cable, the latter going to the office.

If the cable landing is far from the office and the cable must be connected with a land line, the end of the cable should go into a "cable hut." This is a small structure in which the cable comes up out of the trench and is secured to the lightning arrester, the land line leading out from there. Great care should be taken in properly securing the cable terminal, either in the office or cable hut. Bad insulation or poor connections are too often left there, interfering with the working of the line or vitiating the tests.
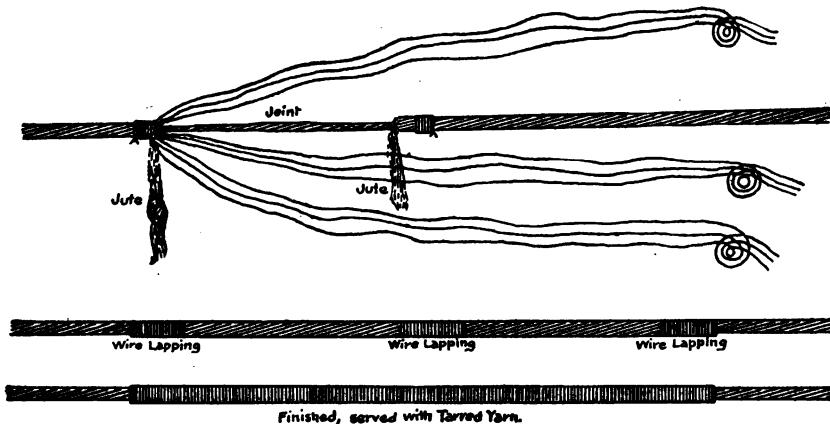
FIG. 2.

SPLICING.

The splicing of submarine rubber cables is an operation which, to do properly, requires great experience and practice.

Ordinarily the cable ship staff attends to such matters; but it may happen at isolated places, like these mentioned on Laguna de Bay, that at least temporary repairs must be attempted.

Having found the fault by some of the tests subsequently explained, and raised the cable with a grapnel, a sufficiently large bight is brought on board and lashed to give length for the splice. The fault having been cut out, the outer serving is removed for about 25 feet back of each end. This is sufficient for a short splice. The armor wires are then carefully untwisted from one end for that length in groups of about five. Tnese should be carefully handled, so they will go back into place easily. (Fig. 2.)

Some small wire, called "seizing," is wound tightly around the cable here to prevent the untwisting from going back any farther. The jute padding is then untwisted and the core is cut off to within a foot of the small wire seizing and the jute about 2 feet from it. Meanwhile a seizing of small wire is wound about 6 inches from the other end of the cable, and the armor wires nicked with a file and broken off close to the seizing. These are then smoothed with the file. The jute is stripped off this short end. The tape is taken off for 6 inches from each end, and the rubber insulation cut in a cone shape with a sharp knife (fig. 17), leaving about 3 inches of conductor exposed at each end. The strands are spread out for 1½ inches, the central wire being cut out of each for that length. The wires are well cleaned with fine emery paper, and the spread-out ends being brought together, they are neatly and closely wound about the twisted parts of each other.

The joints should be soldered, using rosin as a flux. A vulcanized insulation for the joint is always desirable and is considered necessary in deep-sea splices. However, it is impossible to make without the full kit and much experience, so the joint may be finished with the "raw" joint, as it is called by the Western Union cable repair man. Noting that the coned surfaces of the rubber, and for an inch back of these ends, are cleaned and scraped with the knife, take a strip of the black or raw rubber about half an inch wide and 4 or 5 inches long. Holding the end of the rubber strip just back of the cone, wind the strip around the cone and along the wire, making the spirals overlap, stretching the strip with moderate tension. Continue winding until a little beyond the other coned end, then wind back. The strips are thus wound on, back and forth, until the rubber slightly more than fills the space between the coned ends. A clean, warm iron tool should then be rubbed over the joint until the rubber fuses slightly.

It should then be covered with a double thickness of adhesive tape to cover the joint and the portion from which tape was removed.

It may then be slightly warmed with a lamp or warmed tool to complete the fusion of the rubber jointing, care being taken not to overheat it. The jute is then wound back over the joint and secured with a few turns of adhesive tape. The armor wires are then returned to place—they will easily do so if care has been taken in handling them. It will be observed that over 20 feet of the armor from one side will lap over that end from which the armor was not removed. The armor replaced, wires are then bound in place with several seizings of small wire tightly and evenly wrapped. The entire splice should then be served with a closely-wound layer of spun yarn. The proper way of doing this is with the serving mallet (see fig. 2A). Of course if means

are not present to do it otherwise, it should be done by hand. After splicing, the bight should be carefully lowered by small ropes attached to each side of it, to prevent straining or jerking the splice.
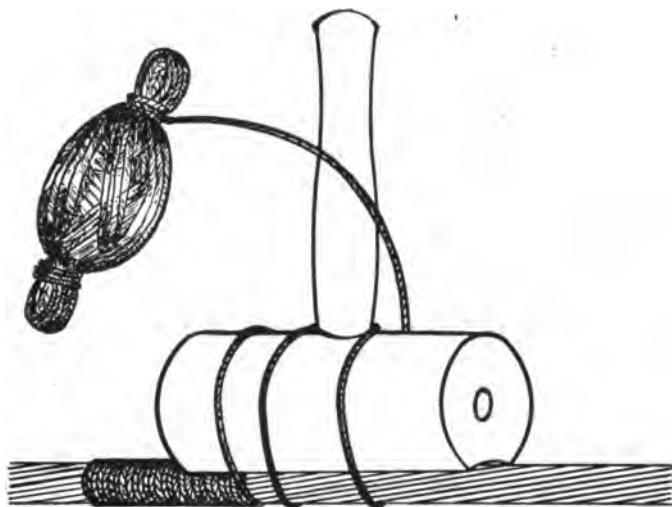
FIG. 2A.—Serving mallet used in putting on spun-yarn serving.

OPERATION OF SUBMARINE CABLES.

SWITCH BOARDS.

As before stated, the cable should, if possible, be brought directly to the switch board.

A special high insulation switch board for cable stations is furnished by the Signal Corps and is shown diagrammatically in fig. 3.

The cable comes in at the upper left binding post. A revolving copper strip is attached thereto, and the base is marked: "Instruments," "Free" or "Earth," corresponding to positions of the strip. This is a useful arrangement in making tests, to conform to instructions from the ship or distant station.

The wire to ground, or to cable leading to the other station (in case this station is a way office) leads to upper right-hand binding post. A disk lightning arrester is connected with a binding post leading to ground wire. The other binding posts are connected with instrument leads in the usual way, and circuits are pegged in as on the land line switch boards. All openings in the wooden case not occupied by wires should be securely pegged up. The wooden case and glass cover protect the hard-rubber base against dust and moisture. During tests, when insulation must be carefully guarded, a small cup of chloride of calcium may be set in the closed case to absorb all moisture.

LIGHTNING ARRESTERS.

The disk, plate, point, and spiral arresters are all "jump" arresters, when the lightning jumps from plates of metal or carbon, or from points or spiral connected with the line to a carbon or metal plate connected with the ground wire. The metal ones are liable to be fused by a flash and should always be carefully examined to see if the line is accidentally grounded by them. Carbon dust is liable to cause similar trouble in those made of carbon plates separated by thin perforated mica. The fuse lightning arresters, in which a short piece of fusible wire is in circuit with the line, arrest the flash by melting off. This, of course, opens the line, and spare ones should always be ready to replace the burned ones. The delicate ones mounted on mica strips with metal ends need to be especially watched. When the line comes open or is grounded, the lightning arresters should be at once carefully inspected.

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GROUND CONNECTIONS.

These should be made with special care at cable stations. The only one which should be made where it is possible is by soldering securely to at least three or four of the armor wires a good-sized copper wire and leading it to the switch board. Where plate ground connections are used, the plate should be copper, of at least 5 square feet surface, with the ground wire soldered securely to it.
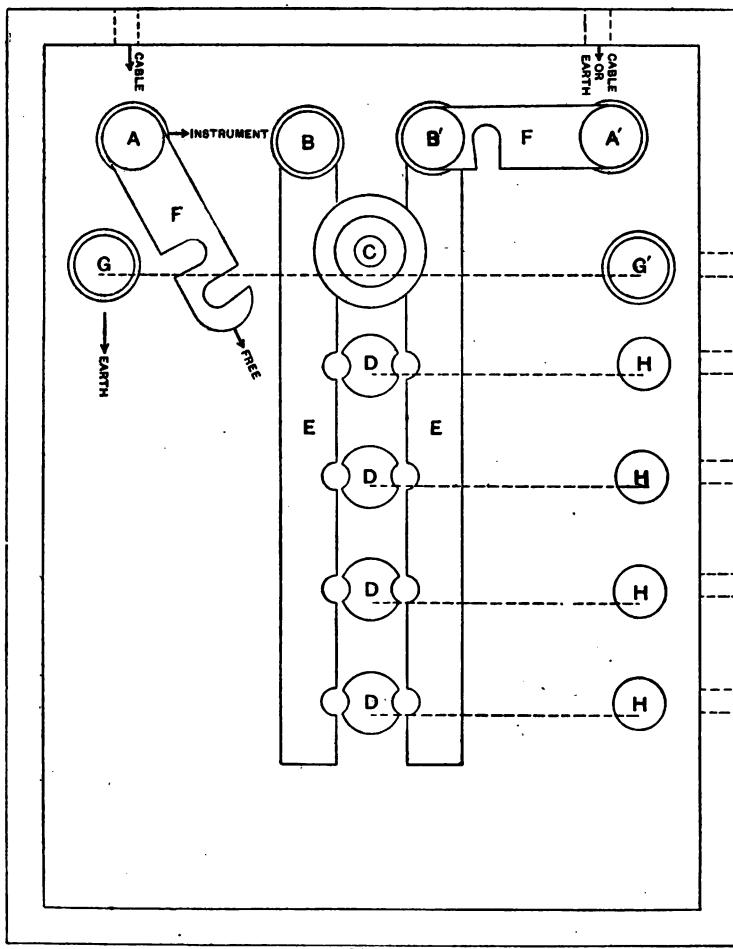
CABLE SWITCH BOARD
FIG. 3.

OFFICE WIRING.

In tropical climates it has been found that the ordinary paraffined office wire is worthless for good insulation. In cable stations nothing should be used but heavily rubber-covered wire. The cable core itself

is a type of the insulation which the wire should have. It will pay to put up the wire with extra care, using porcelain cleats and knobs—never fasten a wire with any of the ordinary staples, which in a majority of instances will be banged down on the insulation, cutting into it and causing bad leaks, which are most baffling to find.

<center>INSTRUMENTS FOR CABLE WORKING.</center>

On cables up to 100 miles in length the conditions for successful working do not depart sufficiently from those of land lines to prevent the use of ordinary Morse instruments. If the cable is sound, the ordinary closed circuit Morse is used, and as long as no incipient fault exists, this method may be used. But with the current constantly on, the least fault in the insulation is rapidly made greater by electrolytic
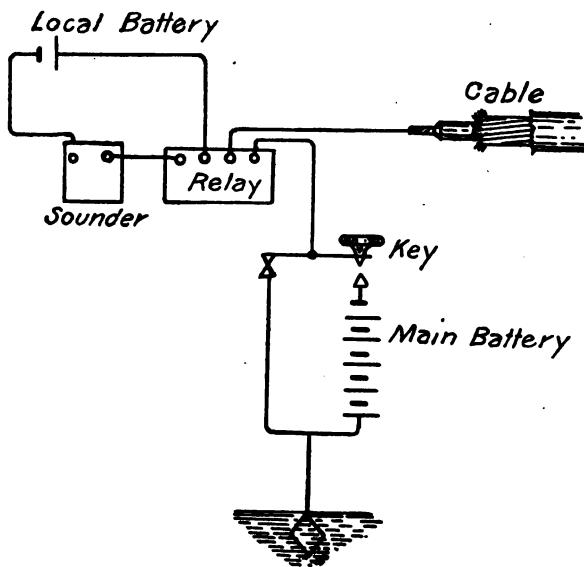
FIG. 4.

action and a break down soon occurs. For this reason the Signal Corps uses the open-circuit system of Morse on its short cables.

A simplified diagram of the open-circuit connections at a station is given in fig. 4.

As will be seen in diagram, the line comes to the relay, thence to body of key, thence to back contact of key, and to the ground. This is the receiving position, and the current from distant stations will operate the relay. When key is depressed, the back contact is broken and the front contact made; this will cause the home battery to be in the circuit and operate the relays.

Special care must be taken not to screw key so close that both front and back contacts touch. This would short-circuit the battery and speedily ruin it.

The polarized relay has two bobbins or pairs of magnets facing each other, with the armature between them. A permanent magnet supporting the bobbins or in the base gives the cores of the magnets polarity opposite to that of the armature, so that the current coming in one direction tends to send the relay tongue to the front contact, and coming in the other to the back contact. Adjustment is made with top screw, as the relay tongue tends to be more or less strongly held by the permanent magnet on the back contact, corresponding to spring adjustment of the ordinary relay. The screws controlling the magnets seldom need any adjustment. Care should be taken that the armature does not jam against the ends of magnets.

A polarized relay is used for two reasons: First, it is more sensitive, and can be worked on less current; second, on account of the large capacity of cables as compared with land lines, the current first charges the cable when the key is depressed; the cable then discharges when key is released, and a momentary current rushes back through the relay. An ordinary relay would give a "kick" corresponding to this, but the polarized relay, responding to the direct current only, is not affected by this momentary discharge current in the opposite direction, and the signals are not "chopped."

The key has a back, middle, and front contact, as shown, the battery being put to line only when key is depressed. The battery used is some form of good open-circuit battery like the Gonda, or large-sized dry batteries.

The sounder should be wound to 6 ohms, to correspond to the higher voltage and lower resistance of the open-circuit type of battery used as a local.

DOUBLE-CURRENT WORKING.

When the cable much exceeds 100 miles in length, it begins to work "heavily" on account of the appreciable length of time it takes for the cable to charge and discharge. A modification of the simple open-circuit method of working, just described, must be made. This is called the double-current method, and in principle consists in connecting an additional main-line battery to the back contact of the key with polarity opposite to the main-line battery connected to front contact. These batteries, by alternately putting opposite poles to line as the key is up or down, serve to discharge the line much more rapidly, and greatly increase the speed of working. A simplified diagram of the connections is given in fig. 5, page 12.

The simple change to make it a plain open circuit set appears when the switch is thrown to *A*. With the key on the back contact, a cur-

rent flows to line from the + pole of back contact battery. When key is depressed the — pole of the front contact battery is put to line. The polarized relays are so connected that they close the local circuit with front contact battery to line. Connections for a three-station line for double-current working are shown in fig. 7.

Without a switch, the back contact batteries would soon be run down. As operators are accustomed to closing the key with the ordinary circuit closer lever, a key is issued by the Signal Corps, obviating the use of a separate switch. The connections are so arranged that the ordinary movements of the switch lever will make the correct connections for the double-circuit system. Other combinations can be made as stated in connection with fig. 6.
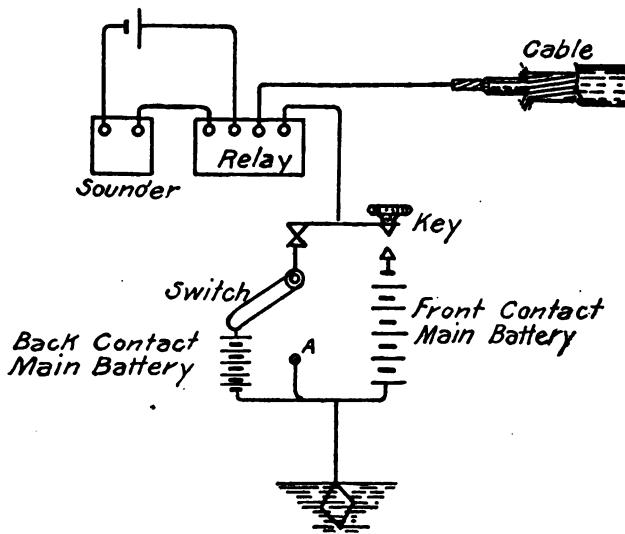
FIG. 5.

SINGLE-CURRENT OPEN-CIRCUIT REPEATER SETS.

[U. S. Signal Corps pattern. 1901 model. Designed especially for use on short cables (fig. 8).]

Mounted on a small table top are the following instruments: Two polarized relays, *AA;* two sounders, *BB;* two open-circuit keys, *CC;* two transmitters, *DD;* one double switch, *E.*

The main line and local batteries for each of the lines, the lines themselves, and the earth are connected to the binding posts marked on the table. These connections, especially those of lines and earth, should be made through the switch board, lightning arresters, etc.

POLARIZED RELAYS.

These are very similar in relation of parts and construction to the square Western Union pattern used on the Philippine cables hereto-
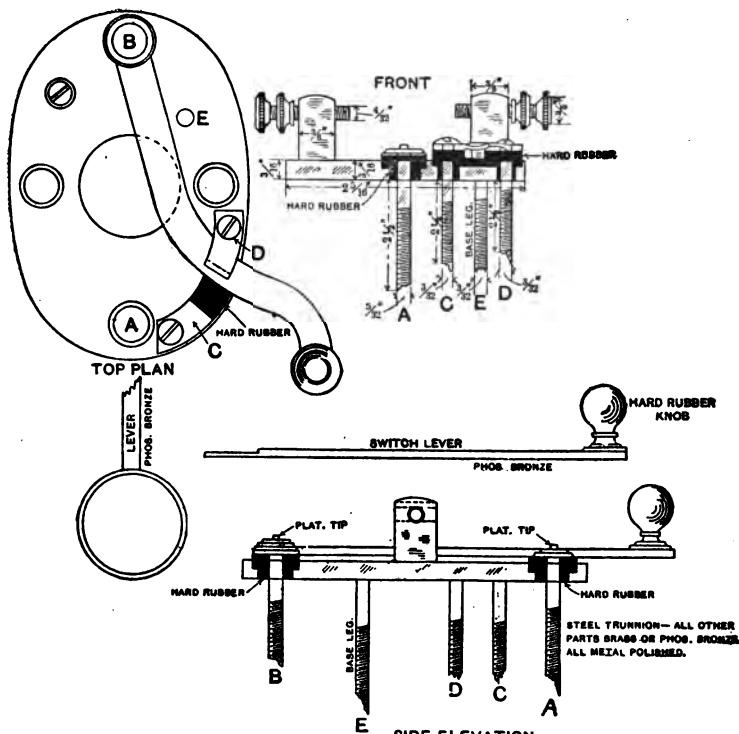
FIG. 6.—Combination key for open or closed circuit (single or double current).

With relay connected to *E*, one pole of main battery to *A*, earth to *C*, and one pole of back contact battery to *D*, the key is suited for open circuit working either single or double current. (Single current with switch closed to left. By opening switch to right the back contact battery is put into circuit for double-current sending). By connecting *A* and *C* together, and *E* and *B* together, it may be used as an ordinary closed circuit key, *A* and *B* being the points connected with line and relay, respectively.
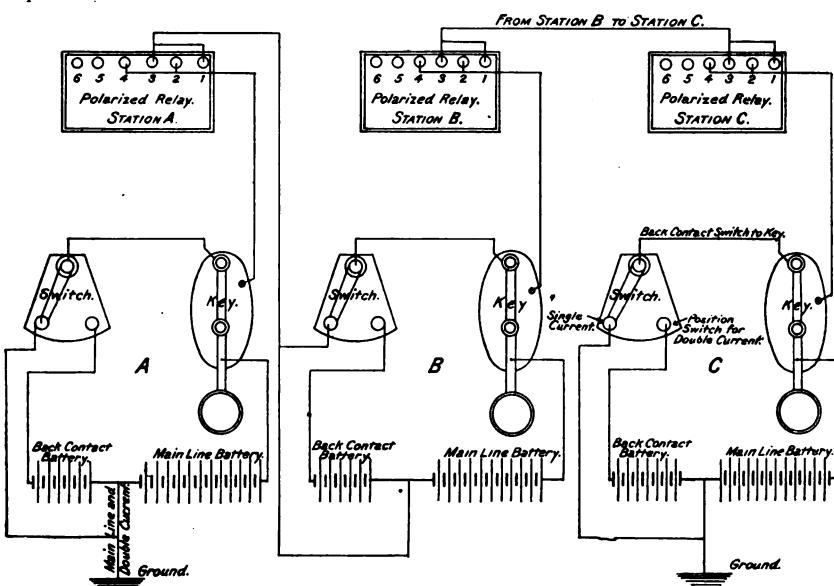
FIG. 7.—Three-station wiring plan, single and double currents sets.

fore, with the addition of a small switch *F* on each, which permits the local to work on either front or back stroke. If the sending comes reversed, throw the switch to the other button.

SIGNAL CORPS REPEATER SET.

SINGLE CURRENT OPEN CIRCUIT.

SEPT. 1901.

FIG. 8.

Adjustment.—The lower adjusting screws on each side should be turned until the magnets are fairly close to the armature, care being taken not to jam them against the armature. The relay tongue can
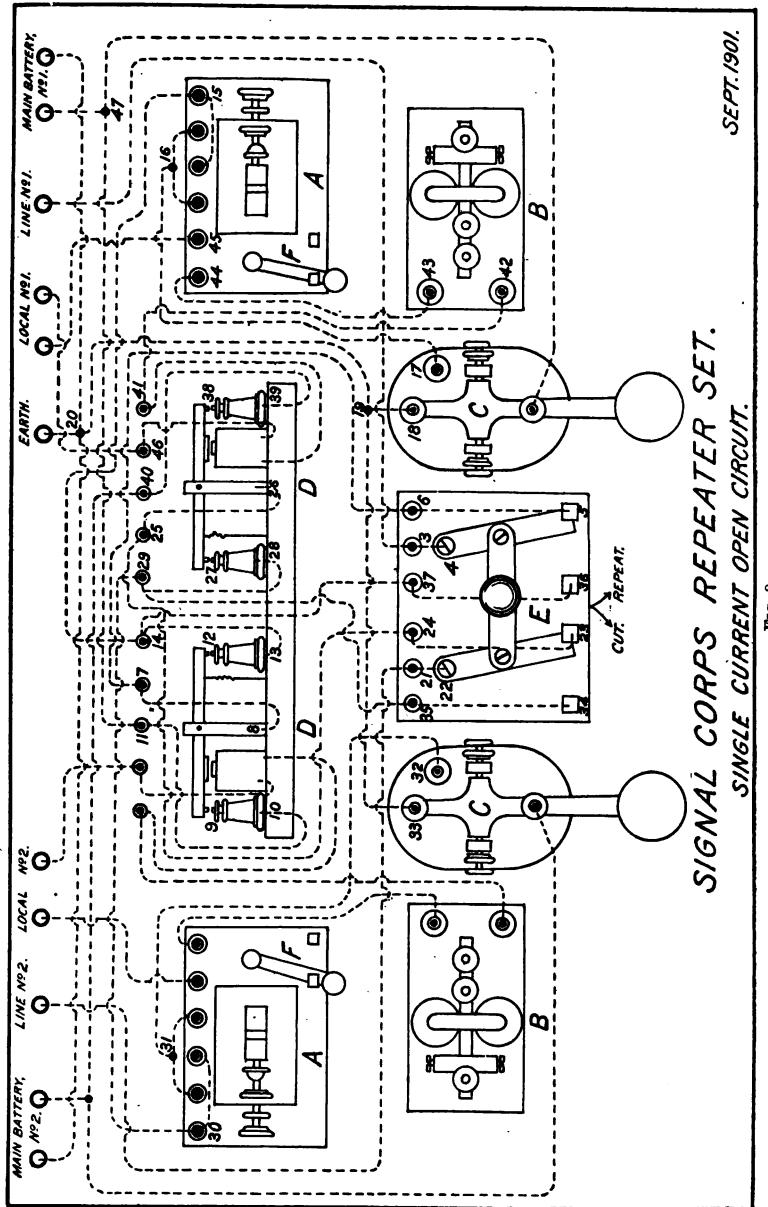
then be caused to fall over to one side or the other as desired by the top adjusting screw. The magnetic retraction corresponding to relay spring can thus be made strong or weak as desired. For repeating, the set works better if the relay tongue has a barely perceptible play.

Before substituting the repeater set for the two office sets find out from each operator at distant ends of both Nos. 1 and 2 lines whether zinc or carbon is connected to the front contact of his key. Suppose No. 1 says zinc. Connect up several cells of battery, put wire from carbon in "earth" binding post of repeater set. Connect two cells in local binding posts of No. 1. Then tapping with wire from zinc on line No. 1 binding post, note if it works the relay No. 1. If not, move the upper adjusting screw until relay tongue just falls over on the other contact, and it should then work it. If your sending "comes reversed" on the sounder, throw the relay switch F on to the other contact.

Proceed in the same way with No. 2, being sure to tap on line No. 2 binding post with the wire coming from same pole of your experimental battery, as reported by distant end of No. 2 as going to line through front contact of key.

Now, having placed the table in position and run the wires from switch board, batteries, etc., to the proper binding posts, place the switch at "cut" and try to work on, say No. 1. If you do not succeed, reverse the wires leading to main battery No. 1 binding posts, and this will probably send the current in the right direction to work both your own and the distant relay.

Proceed in the same way with No. 2 before attempting to move the main switch to the "repeat" position.

SOUNDERS.

These should be adjusted with as little play in the lever as is consistent with sufficient loudness.

TRANSMITTERS.

Each of these has a front and back contact, like the keys; in fact, it is an open-circuit key worked by its electromagnet in the local circuit with the sounder. For good repeating, the lever should have barely a perceptible play. Be careful that the armature does not strike the magnet; this would prevent the "front contact" from being made at the contact points nearest the magnets.

Having made the various adjustments, throw the double switch from "cut" to "repeat." The two lines should then work into each other.

Note that when distant station or key of repeater set is working, say on line No. 1, only that side of repeater set should be working, and similarly for No. 2.

If operators at distant ends complain that it comes very " choppy," note if repeater, relay, and transmitter levers are set to work extremely close, or if the adjustment is not too strong on the relays. Also if the springs in the transmitters are not too strong.

Senders on lines tied together by repeaters should be cautioned that light "jerky" sending is particularly hard to get through repeaters well.

DESCRIPTION OF OPERATION OF OPEN CIRCUIT SINGLE CURRENT REPEATING SET.

First, suppose distant station on line No. 1 is working, the double switch set to "repeat." The current comes in line No. 1 binding post, thence to 3 and 4 to right bar of switch, through contact 5 to 7 and 8 on left transmitter, through lever of transmitter to "back contact" 12 and 13, through 14 to relay at 15, through relay coils operating the relay tongue, then out at 16 through 17 on key, through body of key to 18, 19, and 20 to earth. The local circuit being closed at relay, the local battery sends in a current through binding posts local No. 1, thence to magnet of transmitter, through 46, out at 41, through sounder at 42 and 43, through relay local points at 44 and 45, thence back to local No. 1 battery. When the local current passes through transmitter magnet it closes the "front contact." This permits the current of main line battery No. 2, starting at binding post, coming to transmitter on 40, to "front contact" 39 and 38 through lever of transmitter to 26, then to 25, to switch contact 23, through 24 to left bar of switch, to 22, 21, and to line No. 2 binding post, out to line, working the instruments in that line. An exactly similar thing happens when an operator in line No. 2 sends a current through his side of the repeater set.

When the repeater station works his key on the No. 1 side, a current comes from No. 1 main-line battery left binding post to the front contact of his key through 47, thence through key lever to body of key, then to relay No. 1 through 17, through relay and out to line No. 1, through 16, 15, 14, 13, 12, 8, 7, 6, 5, 4, 3, to "line No. 1" binding post, and out to line.

Relay No. 1 works its local circuit, causing the transmitter to repeat into line No. 2, as before explained.

When switch is turned to "cut," each key, relay, and the transmitter and sounder in local circuits work independently as two ordinary open-circuit sets.

Two small resistance coils under the board are arranged to "bridge" the sounder and transmitter magnets of each set. This prevents sparking and sticking at the local relay points.

NOTES ON MUIRHEAD CABLE INSTRUMENTS.

The recorder (fig. 9) consists, essentially, of a strong, permanent magnet between the poles of which is, vertically pivoted, a small, light coil of many turns of fine wire. This coil is connected with the outside circuit through two very fine spiral wire terminals below it. This coil is tied to the aluminum siphon cradle with two fine silk threads. This siphon cradle is suspended with phosphor bronze wires whose tension is altered to the screw above them. Two small handles serve to adjust the inclination of the coil and cradle, and the position of the siphon point on the moving tape.
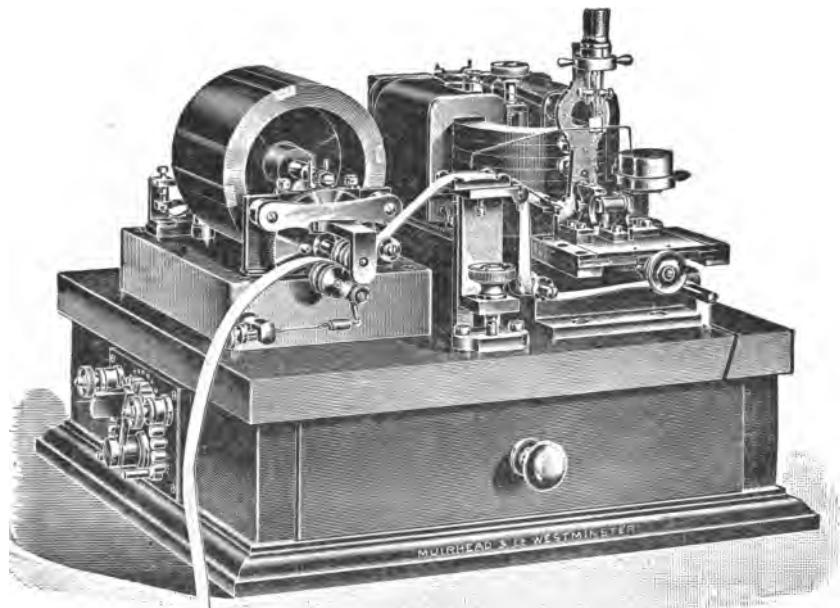
FIG. 9.

The siphon is of minute bent glass tubing and dips into an ink well at one end. The height of the ink well can be adjusted by the handle attached to it. The siphon is attached to (or detached from) the cradle by warming a brass wire and melting with it the wax holding the siphon.

The "mill" or motive power is a simple drum motor, which is driven at proper speed by two storage cells. The terminals are at the end with lowest numbers under the speed-controlling switch.

If storage cells are not available perhaps the best substitute are the Edison (or Edison-Lalande) cells in enameled steel jars.

It will require about 6 in series to give the requisite voltage, as many rows of these as necessary to give requisite capacity for steady current. Of the small sizes ordinarily furnished, about 3 rows of 6

in series—18 cells—will be about right. If the ordinary bluestone
cells are used, about 5 should be in series, and 6 rows of these, or 30
in all, will be required.
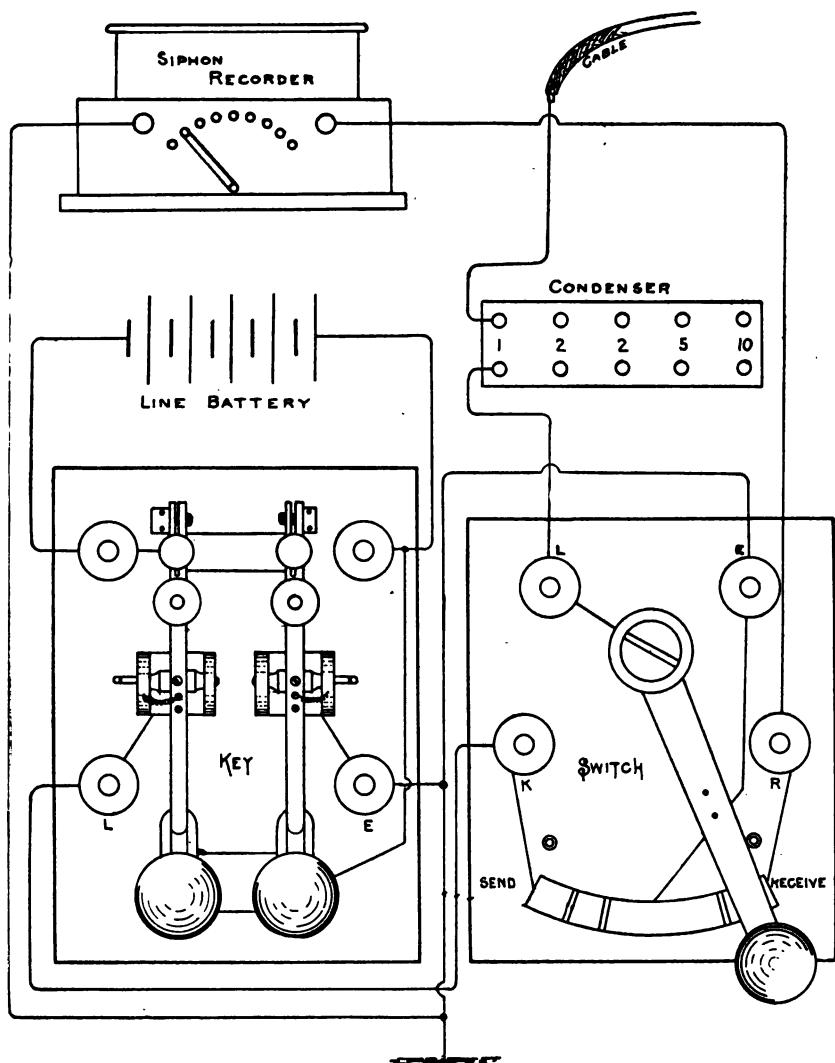
Station Connections
Siphon Recorder Cable Set. *Ground* Recorder operated by distant station only.

Fig. 10.

The vibrator binding posts need not be considered, as the vibrator
(controlling small magnet under the siphon cradle) is not needed on
the short Philippine cables. The binding posts, marked + (copper) and
− (zinc), by the vibrator posts, are for attaching battery in case the

permanent magnet is weakened and requires strengthening. It requires about 100 volts to do this effectively. If the recorder, with normal amount of current passing, still shows feeble signals, current should be sent through it, as indicated, several times for a few seconds at a time.

No mistake should be made in attaching the carbon or copper terminal to the + binding post and to use the proper number of cells in series to give about 100 volts. If 110 volts of constant current electric supply is available it may be used, being sure that the current goes in right direction through the coils around the magnets.

The line wire (through switch) and ground wire are attached to the end of the recorder opposite the motor connections. There is a small shunting switch here, by which the signals on the tape may be varied in size, the higher numbers giving least shunting and signals of greater amplitude.

GENERAL SCHEME OF CONNECTIONS.

See diagram (fig. 10) page 18.

The 20 microfarad Muirhead condensers are connected as shown, one side to the cable and the other to the switch. By interposing these condensers at each end of the cable, nearly all bad effects from earth currents are avoided, and much sharper signals are obtained.

If signals come from distant station reversed, the obvious remedy is for distant station to reverse its line battery.

Ground connections.—In no case should the recorders be connected with the same ground as land lines, or even to the same cable sheath that connect to instruments where Morse is used. Owing to the great delicacy of the recorder this will cause the Morse working to disturb the recorder signals.

NOTES ON RECORDERS, AUTOMATIC TRANSMITTERS, ETC.

[A. G. Williams.]

RECORDER SIPHONS.

A lighted paper spill made of recorder tape is a handy means of bending siphon tubes and can be used after a little practice by anyone with an idea of true proportions. A small spirit lamp is better. Tilt the lamp forward; the tubes must not be thrust into flame; a slight contact with the blue flame underneath will bend the tubes without melting and closing the tube. By using a spirit lamp both hands are available.

The best way of breaking off the surplus tube is by pressing it between the thumb nail and the forefinger; this usually leaves a clean level break requiring very little grinding. A fine emery stick is the handiest means of smoothing the siphon point.

When recorders are not in use for any time, the siphons should be immersed in water instead of ink. Empty ink well, fill with water, letting paper tape run till all ink is drawn out. Better still is the use of alcohol instead of water. When ink is drawn out of siphons, the alcohol filling tube, the alcohol can be returned to bottle and siphon left dry. On starting recorder again the ink will flow freely without assistance, the alcohol having evaporated leaves tube dry. Ink used for siphon is usually made from aniline powder. A small spoonful will make a pint. Use boiled water in making ink. This prevents any ferment or thickening of fluid. Keep bottle well corked. Add a little spirits of wine (alcohol) to ink. This causes it to dry quickly on tape and also keeps ink flowing more freely. Aniline ink does not corrode the apparatus, hence its use. Ordinary ink can be used on a pinch. Diamond dye makes a good ink. Aniline can be obtained in boxes of one or two pounds. Such a quantity will last for some time and should form an important part of station outfit.

If siphon gets choked, heat the wax soldering strip used for putting siphons on, gently rub along siphon. This will force the ink out and remove the obstruction.

The automatic apparatus and perforators can be most conveniently cleaned by dipping and rinsing in kerosene oil and allowed to drain. This will, to some extent, obviate the necessity of taking them apart and will not injure them. Be careful and do not oil the regulating disks at the back of automatic transmitter inclosed in the round box. See that they are quite dry, otherwise they will slip and cause uneven running. All working parts to be kept slightly oiled and carefully wiped of all superfluous oil. See that the keys and transmitter levers are equally adjusted with exactly the same play. The signals will thus come out evenly and regular. The perforator knives require sharpening after a time. This is done by an emery wheel. They must be ground on the side of wheel; a perfectly flat surface is required; the edge does the cutting. The sharpening is more to polish the surface and must not be continued any longer than needed, as this will shorten the length of spindles.

There are six terminals on automatic transmitters, four at back marked *C. Z. L. E.* and two at end marked key *L. E.* Trace switch under automatic transmitters; the operation will then be understood.

If an operator is detailed to check messages in transmission by sound and a recording instrument, the necessity for repeating back will be obviated.

CARE OF PAPER USED IN PERFORATORS.

The rolls of paper tape often become damp in store. If this occurs, it will be found the holes are not clean-cut by the perforator. This means signals will not pass, as spindles will not be forced through the

slightest obstruction. The remedy is: Dry the rolls in a slow oven or other means, so that the rolls become looser and dry, and thus cut easily.

A stoutly made table, 6 by 3 feet, will accommodate two perforators, key, automatic transmitter and recorder, and terminal posts, so that all connections are simplified; the tape falling over edge of table from recorder and the automatic transmitter; the receiving tape passing over a small bridge from recorder in front of receiving operator.

The tape can be better wound by hand, as instructed. The hand-wound tape is more compact and tightly rolled up; less liability to fall apart and cause endless trouble in case the slip has to be referred to at any future date. Moreover, it takes up little space in pigeonholes. The pigeonholes should be large enough to hold rolls for one week, and dates should be placed on slips and pigeonholes, so that they may be easily found for reference. A corresponding pigeonhole for messages will also be convenient and will simplify matters.

The perforators and automatic transmitters to be placed on one side of the table, the key to be movable, mounted on a hard-wood base with about 4 feet of flexible covered wires, so that it can be used either one side or the other on table. The perforated slip or tape must be also wound by hand. If two punchers are employed, the tapes can be wound on one roll and dated the same as recorder rolls.

It is advisable to have terminals or binding posts of line, earth, batteries, etc., in a convenient position on table so that all connections to apparatus can be easily seen and as easily connected to the various terminals on instruments.

The automatic transmitter must be placed over a corresponding oblong square hole so as to allow room for chain and weight to work freely; a box-shaped guard to cover weight and chain so as to prevent injury in case chain breaks.

DIRECTIONS FOR ADJUSTMENT OF MUIRHEAD'S IMPROVED CABLE PERFORATOR
(LATEST FORM—FIG. 11).

The hammers are so arranged that, instead of striking as before on a side pin connected to the punch, they strike on the punch itself, thus not only giving a straighter blow to the punch, but doing away with the friction of the side pins.

The front steel plates are steady-pinned together, so that they can be fixed or removed without fear of the holes in them not coming opposite.

The punches are constructed so that the cutters, or front portion of them, can be easily withdrawn when blunt and new ones inserted without having to take the punch block to pieces. The cutters are secured
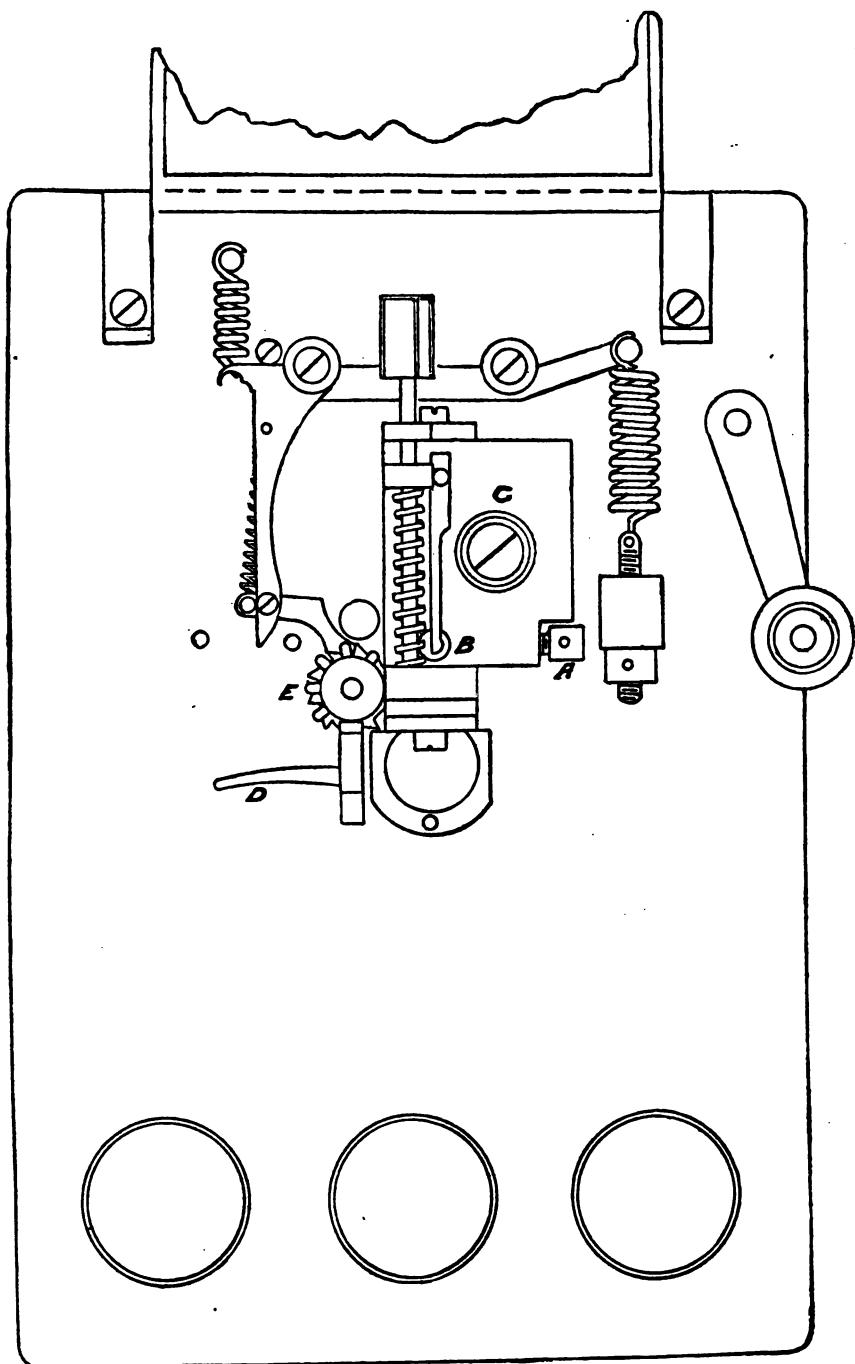
Fig. 11.

to the punches by means of spring fittings. By removing the punch block from the base of the perforator and pushing the punches forward until the cutters are well through the holes in the front steel plates the cutters can be easily gripped by a pair of pliers and pulled out. When inserting new cutters, see that they are pushed well home into their spring fittings and take care that the rounded ends of them enter first.

The adjustment for spacing is now placed on the punch block itself. A blue capstan-headed screw A will be found on the right-hand side playing against a spring steady pin B. If this screw is turned to the right, the space is lengthened; if to the left, it is shortened.

Before making this adjustment the clamping screw C must be released half a turn and then reclamped when the adjustment is completed. This arrangement permits of the roller being reduced to half size and weight, smarter paper action being the result.

To start a fresh roll of paper, first pull the front arm D forward, then push the paper between the front steel plates and between the roller and the front arm, and finally let the front arm go to press the paper on the spurs of the ratchet wheel E. A little help is always required for the first three holes by pulling the paper gently while striking the tappers.

CABLE TESTING.

The remarks made under the heading "Testing" concerning the general necessity for testing regularly apply with added force in the case of cables. By applying regular tests incipient faults will frequently disclose themselves long before they become sufficiently serious to interfere with the working, giving ample time to notify the repair ship, if the faults are out at sea. Furthermore, it is absolutely necessary in case of cables to locate them accurately by tests, though this part in its refinements belongs in general to the cable-ship experts. The subject of cable testing is extensively entered into by Kempe in his *Handbook of Electrical Testing*.

The works already cited by Wilkinson and Bright also describe various methods. *Students' Guide to Submarine Cable Testing* (Fisher & Darby), *Electrical Testing for Telegraph Engineers* (J. Elton Young), and *Testing of Insulated Wires and Cables* (Webb) are recommended treatises on testing. The Students' Guide and the latter are compact treatises which are quite elementary and easily understood.

It is proposed to describe such tests as are usually desirable at cable stations, leaving the description of complicated apparatus and methods, together with the mathematical demonstrations, to the works cited. For the more elaborate tests required on cables of over 200 miles in length reference is made to the standard works quoted.

In making the approximate measurements at stations the Weston milliammeter and voltmeter set may be used. These, of course, will not give sufficiently accurate results when high resistance faults exist. The Wheatstone bridge may be used whenever measuring the ordinary resistances, and the ohmmeter will answer for approximations. The Fisher cable-testing set, described on pages 46–58, combining as it does so many necessary instruments, is exceedingly convenient.

The reflecting galvanometer is a necessity in accurate cable measurements. Not only does it give better results than any other form with Wheatstone bridge measurements, but it is a necessity in insulation resistance and capacity measurements, both of which are very important in cable work. Before going into them the reflecting or mirror galvanometer will be described.

REFLECTING GALVANOMETERS.

Any pointer or indicator attached to the movable coil or needle of the galvanometer increases the mass to be moved and decreases the sensitiveness. A delicate mirror being attached to the coil or needle may be used to reflect a beam of light onto a scale, thus giving a weightless pointer or indicator as long as may be desired and consequently great sensitiveness. Another way of utilizing the reflecting principle is to view the reflected image of the scale with a small telescope, noting the number on the scale intersected by a vertical thread in the telescope. Formerly, the Thomson reflecting galvanometer (fig. 12) was exclusively used for any case requiring great sensitiveness.
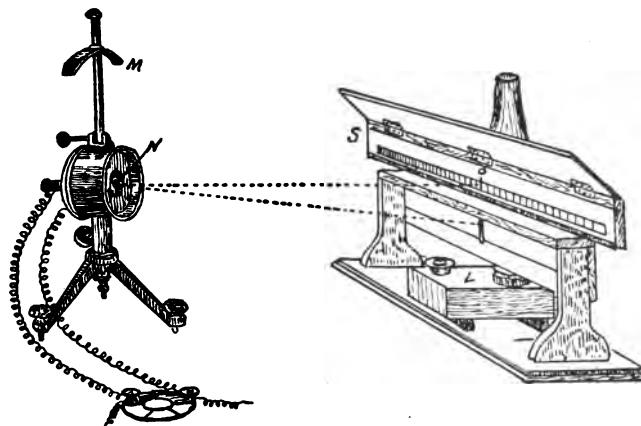
Fig. 12.

The beam of light from the lamp L shining through the slit in the shield is reflected from the mirror attached to the suspended magnetic needle N and is projected on some point of the scale S.

The needle swings in a small space in the middle of the coils, and the direction and strength of the controlling force is given by the bar magnet M. By this arrangement it is seen that a very small movement of the needle and the attached mirror will be greatly magnified in the movement of the spot of light on the scale.

Galvanometers of the D'Arsonval class, with a suspended coil turning in the field of a permanent magnet, are in general use for all kinds of measurements. While usually not of such a high degree of sensitiveness as the Thomson, they are much more "dead beat" and manageable. These are quite generally used as mirror galvanometers.

An excellent portable form for cable station use is shown in fig. 13. As will be noted, these use the small telescope to view the scale, and
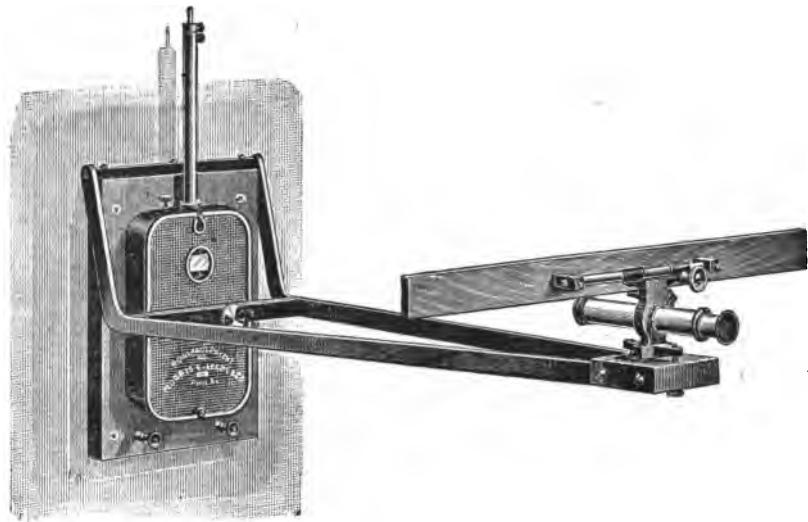
FIG. 13.

should be so mounted that the light from the window or lamp will fall on the scale.

SHUNTS.

Any delicate galvanometers like the above can not be used in most cases with the whole current involved in the measurement, as even through a very great resistance a single cell will cause the reflected
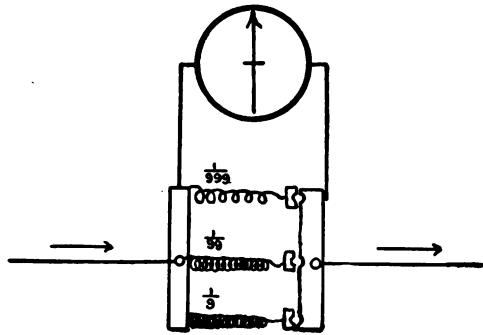
FIG. 14.

image to move completely off the scale. Consequently, shunts are provided which allow certain definite portions of the current (usually $\frac{9}{10}$, $\frac{99}{100}$, or $\frac{999}{1000}$) to pass through the shunt, and $\frac{1}{10}$, $\frac{1}{100}$, and $\frac{1}{1000}$, respectively, to go through the galvanometer.

The simplified diagram is given in fig. 14.

By placing the plug at one or the other of the points a divided circuit is formed and a certain part of the current will flow through the shunt and the other through the galvanometer. For example, $\frac{1}{9}$ has $\frac{1}{9}$ as much resistance as the galvanometer. So $\frac{99}{100}$ of the current will flow through this and $\frac{1}{100}$ through the galvanometer. Hence, the deflection with this shunt will be only $\frac{1}{100}$ as much as it would be if no plug were put in the shunt, thus bringing the deflection within readable limits.

The Ayrton universal shunt is now frequently used with galvanometers of moderate resistances. One of these can be used with any galvanometer regardless of their relative resistances, and it has the
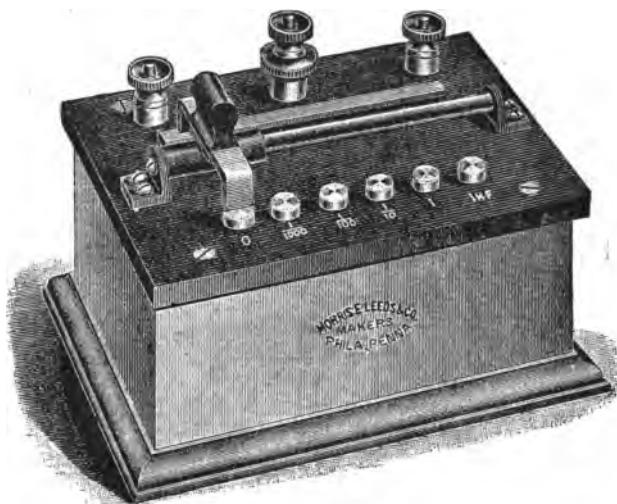
FIG. 15.

advantage of being accurate for condenser and capacity measurements as well. In this the shunts are more conveniently marked $\frac{1}{1000}$, $\frac{1}{100}$, $\frac{1}{10}$, 1. This form of shunt is now largely used and highly recommended. (See fig. 15.)

INSULATION RESISTANCE.

The use of reflecting galvanometers in making the important measurements of insulation resistance will first be considered. On account of the immense insulation resistance of short pieces of cable running up into many million ohms, the million ohms is adopted as the unit in insulation measurements, and is called the megohm. The Signal Corps standard submarine cable is usually specified to have 1,400 megohms insulation resistance per mile, measured at 60° F. As will be seen

by the table (pp. 64–65), this resistance decreases quite rapidly as the temperature rises.

Before proceeding with insulation measurements it is necessary to get the "constant" of the galvanometer. If the piece of cable to be measured is short, its insulation resistance will probably be very high, and a battery of from 50 to 100 cells in series will be required. These may be the smallest size dry cells, or one of the regular boxes of testing batteries. It is the experience of the writer that these latter are an expensive luxury on account of their first cost and liability to be ruined by even very brief short circuiting.

The galvanometer (G), shunt (S), short-circuit key (K), reversing key (C), high resistance 100,000 or 1,000,000 ohms (R), and battery
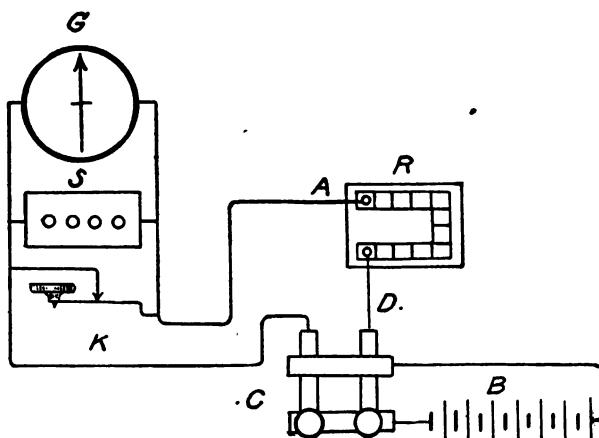
Fig. 16.

(B), are connected up as shown in fig. 16. In this and subsequent measurements the Ayrton shunt is assumed as used, and the shunts designated as $\frac{1}{10}$, $\frac{1}{100}$, and $\frac{1}{1000}$.

The highest figure of shunt ($\frac{1}{1000}$ of Ayrton) should be used first, and after depressing either lever of reversing key the short-circuit key is tapped.

If the galvanometer is greatly deflected, the amount of battery should be cut down until a deflection of, say, 100 to 150 divisions of the scale is noted when keys are depressed. Suppose 10 cells of battery with the $\frac{1}{1000}$ shunt gives a deflection of 125 through the standard resistance of 100,000 ohms ($\frac{1}{10}$ megohm). Then the "constant" is

$$\frac{125 \times \frac{1}{10}}{\frac{1}{1000} \times 10} = \frac{1,000 \times 125}{10 \times 10} = 1,250.$$ This means that one cell of the kind of battery used will give a deflection with the unshunted galvanometer of 1,250 division of the scale through 1 megohm. Or, as it

is usually stated, will give one division of the scale deflection through 1,250 megohms. The insulation of the leads and instruments should now be tested by disconnecting the wire at A and noting if there is any deflection when keys are pressed, trying each lever of reversing key.

Having obtained the galvanometer "constant," the preparation of the cable for insulation measurement must be made. If the cable is coiled, both ends must be carefully prepared. If it is a cable laid and in use, the distant end must be carefully prepared and insulated as described.

The armor, jute and tape having been stripped off for at least a foot from the end, the rubber is scraped clean for about 6 inches from the end, and near the end the rubber is cut away with a sharp knife to a conical form. (See fig. 17.)

After preparing, great care should be taken not to touch the coned end or several inches back of it with the fingers or anything which may cause surface leakage by forming a film over the freshly prepared surface. As an additional precaution the coned end may be slightly warmed by the flame of an alcohol lamp just before the measurement.

FIG. 17.

If the cable is in a coil it is best to carry both ends of the conductor to A, as shown in figure 18, and connect D with a brightened place on the armor wires, this being an effectual way of putting D to "ground." The correspondence of figure 18 with figure 16 is seen, in that the ground (or sheath) and cable conductor take the place of the terminals of the high resistance box. If only one end of the cable is easily available, the other end must be placed with the exposed conductor and cone not touching anything.

Having completed the connections as shown, it is well to make a preliminary test with a few cells, pressing the keys as in obtaining the constant to make sure there is no serious leak which might give so violent a deflection as to injure the galvanometer. Use a high shunt at first ($\frac{1}{1000}$) and make a test. Begin by depressing the right-hand lever of the reversing key (giving "zinc to line"), wait a few seconds, and then press the short-circuit key. The deflection will be greater at first, becoming almost steady at the end of a minute. If the deflection is very small decrease the shunt to $\frac{1}{100}$; if still very small, $\frac{1}{10}$; and,

finally, if still small, remove the shunt entirely (⊦). If it is still some-what small more cells may be put on.

"Electrification" causes insulation to rise markedly for the first few seconds, and more slowly later, the effect becoming practically imperceptible after a few minutes. Insulation measurements specified are usually at the end of one minute. So, after preliminary tests, let the cable stand for several minutes and completely discharge, then depress "zinc" end of reversing key, noting the time. A few seconds later depress the short-circuit key. The deflection will virtually cease changing at the end of a minute, when it is noted, and the insulation resistance per mile may be worked out.

For example: Piece of "Safety" rubber cable 2 miles long in tank;
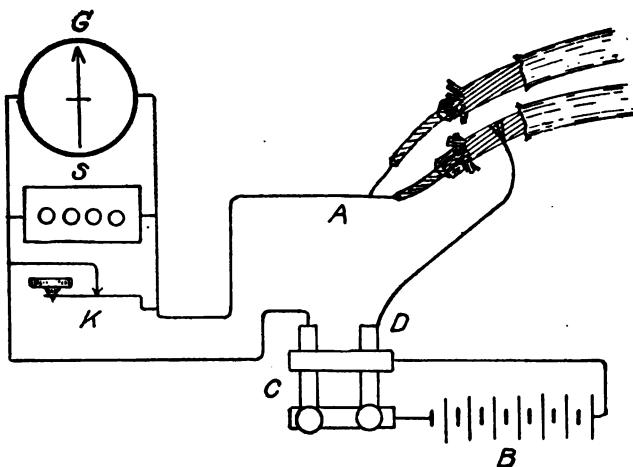
FIG. 18.

40 cells, dry battery; no shunt; galvanometer constant, 1,250; deflection at end of one minute, 120;

If N = number of cells,
G = galvanometer constant,
S = value of shunt used,
M = number of miles of cable tested,
D = deflection at end of one minute after closing circuit,

Then,

$$\text{Resistance per mile in megohms} = \frac{N \times G \times S \times M}{D}$$

$$\frac{40 \times 1,250 \times 1 \times 2}{120} = 834 \text{ megohms per mile.}$$

Taking a case in which the insulation resistance is low, due to deterioration—suppose with 10 cells and a shunt of $\frac{1}{10}$, a deflection of 145 is given in a piece of cable 1½ miles long.

$$\frac{10 \times 1,250 \times \frac{1}{10} \times 1\frac{1}{2}}{145} = 143 \text{ megohms per mile.}$$

Tests should also be made with carbon (or copper) to line by depressing left lever of reversing key. If the cable is sound, little or no difference in deflection will result. If faulty, the zinc to line usually gives the greater deflection. In all cases careful record should be made of the temperature of cable tanks or coil of cable. Reduction may be made to standard temperature, as shown in tables on pages 64–65.

TESTING WITH TELEPHONE RECEIVER AND BATTERY.

In the absence of better instruments, a fairly good idea of the insulation resistance of a cable may be arrived at by means of a battery and telephone receiver, as described below.

A telephone receiver (T) is connected with the battery (B) of a few cells, the latter being connected with the cable armor at C. A well insulated wire (I) is connected with the other terminal of the telephone. The ends of the conductor are prepared and insulated as before described. When the end of I is touched on the cable con-
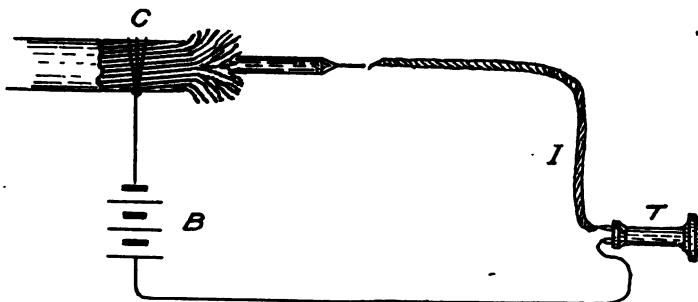
FIG. 19.

ductor a click is heard in the receiver. If after about one second it is touched again and no click is heard in the receiver, the insulation resistance, if one cell of battery is used, is about fifty megohms; if two cells of battery, 100 megohms, and so on for about the proportion of cells.

The click produced on first contact is due to the current rushing in to charge the cable; and if the insulation is good, in one second so small an amount of this charge will be lost by leakage that little or no sound will be produced by subsequent contacts, as cable will still be charged. Care should be taken that wire I and telephone terminal attached to it are well insulated, otherwise leakage from them may give false indications. (The foregoing is a method suggested by Mr. Henry W. Fisher.)

TESTING WITH MAGNETO.

It should be remembered that a good magneto and bell will ring through a cable when connected to armor and conductor where the

capacity is 0.1 microfarad or more, even when the insulation is perfectly sound. Its indications are therefore not reliable when the cable is over a few hundred feet in length.

MEASUREMENTS OF CAPACITY.

This is of relatively small importance on land lines, and capacity effects are but little noticed in telegraphic work except on very long lines. The capacity per mile of cables is so much greater than that of land lines that the retarding effects are soon noticed. Measurements of it should be made in the regular tests of the cable; and in case of a break, with no ground connection at the broken end, as quite frequently happens with rubber cables, by measurements of capacity we may locate the break. As previously noted, the unit of capacity is the farad. But as this is inconveniently large, one-millionth of it is
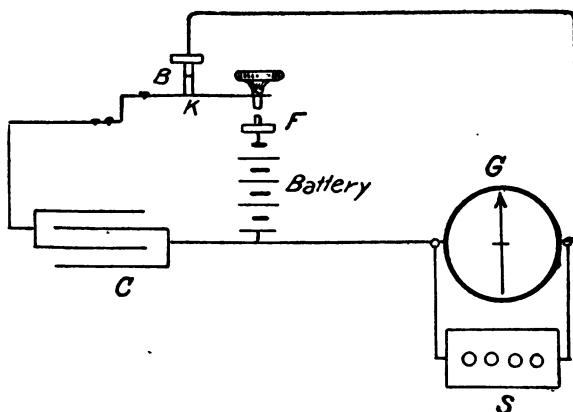
FIG 20.

the unit practically used, called the microfarad (abbreviated frequently to m. f.). To give some idea of the microfarad, it may be noted that this is about the capacity of 3 miles of ordinary submarine cable, and the ordinary sizes of the small box condensers referred to under telephone buzzer and duplex telegraphy are from one-third to 1 microfarad. The standard 1-microfarad condensers used in measurements is made up of tinfoil and mica sheets, instead of tinfoil and paper, and can usually by means of the plugs be subdivided into fractions of a microfarad. Above are shown the connections of a standard condenser with a battery and a mirror galvanometer.

The connection being made as shown (fig. 20) with battery, condenser (C), galvanometer (G), shunt (S), key (K) having a front contact (F) and a back contact (B). When key is depressed the battery will charge the condenser. When key is released a momentary deflection is produced by the discharge of the condenser through galvanometer and shunt.

By adjustment of the shunt, capacity in the condenser, and number of cells in series in the battery, the deflections may be varied. In general the relation between capacity K, number of cells (electromotive force) N, value of shunt S are such that deflections within moderate limits are proportional to the product of N, K, and S.

For example, if a one-half-microfarad condenser is connected up as shown with 10 cells dry battery, and the galvanometer has a shunt of one-tenth, and suppose the deflection or "throw" (extreme limit to which the coil or needle swings when condenser is discharged) to be 210.

Now, put in an unknown condenser (X) with same battery and shunt and take a "throw." Suppose it is 105:

$$210 : 105 :: \tfrac{1}{2} \times 10 \times \tfrac{1}{10} : X \times 10 \times \tfrac{1}{10}$$
$$210\,X = \tfrac{105}{2}.$$
$$X = \tfrac{1}{4} \text{ microfarad.}$$
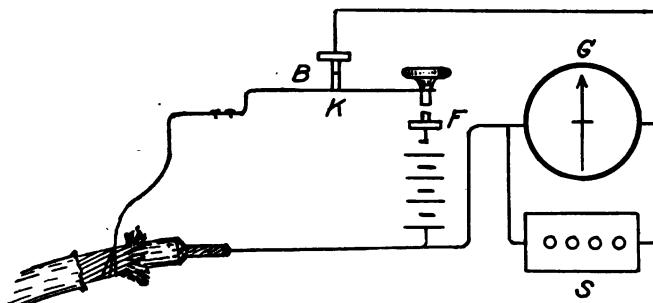
FIG. 21.

Suppose in the second case a large condenser were used and the "throw" went off the scale even with the $\tfrac{1}{10}$ shunt. Then using, say, $\tfrac{1}{100}$ shunt and 5-cell battery, suppose "throw" was 50:

$$210 : 50 :: \tfrac{1}{2} \times 10 \times \tfrac{1}{10} : X \times 5 \times \tfrac{1}{100}$$
$$\tfrac{210}{20}\,X = \tfrac{50}{2}; \quad X = \tfrac{25}{105} = 2.38 \text{ microfarads.}$$

To measure the capacity of a cable (less than 250 miles in length) we may proceed as follows:

First, find the deflection with a condenser of known capacity as just stated. Then connect up as shown in fig. 21, in which the cable and ground (its sheath) are substituted for the two condenser connections. The other end is prepared as for measurement of insulation resistance.

For example: As before, suppose deflection D is 210 and N, K, and S are, respectively, 10, $\tfrac{1}{2}$, and $\tfrac{1}{10}$; length of cable is 4 miles (L). Deflection (D'), when connected as shown in fig. 21, is 275, using 5 cells and same shunt $\tfrac{1}{10}$. What is capacity of cable per mile?

$$D : D' :: N\,K\,S : N'\,L\,X\,S'$$
$$210 : 275 :: 10 \times \tfrac{1}{2} \times \tfrac{1}{10} : 5 \times 4\,X \times \tfrac{1}{10}$$
$$X = 0.32 + \text{microfarad per mile.}$$

In this, as in all the measurements of cable coiled in tanks or else-
where, record of temperature should be carefully made at the time of
measurement.

CONDUCTOR RESISTANCE.

This is usually called "copper resistance" (C. R.) in books on cable
testing.

To measure the resistance of sound cable when it is coiled in the
tanks, when both ends are available the methods before given and
cited in reference books may be followed. Of course, the most satis-
factory and accurate method is with some form of Wheatstone bridge
and mirror galvanometer when these instruments may be had. Good
approximations may be made with the ohmmeter, or the combination
of voltmeter and milliammeter, as stated in land line testing. It is
evident that if we have the resistance of the cable per mile, and find
by methods just stated the total resistance of the coil, the length of
the cable is equal to the total resistance divided by the resistance per
mile. This method is called to attention because of its constant use
in determining the lengths of pieces of cable in the coil. Of course
the temperature must be taken into account, and the resistance meas-
ured must be reduced to that at the temperature at which the resist-
ance per mile is stated. A table of temperature coefficients is given
below.

Temperature coefficients for copper resistance.

Difference in degrees—		Coeffi-cient.	Difference in degrees—		Coeffi-cient.
Fahren-heit.	Centi-grade.		Fahren-heit.	Centi-grade.	
1	0.5	1.002	16	8.9	1.034
2	1.1	1.004	17	9.4	1.036
3	1.7	1.006	18	10	1.0385
4	2.2	1.008	19	10.5	1.041
5	2.8	1.010	20	11.1	1.043
6	3.3	1.013	21	11.6	1.045
7	3.9	1.015	22	12.2	1.047
8	4.4	1.017	23	12.7	1.049
9	5	1.019	24	13.3	1.051
10	5.5	1.021	25	13.8	1.054
11	6.1	1.023	26	14.4	1.056
12	6.6	1.025	27	15	1.058
13	7.2	1.0275	28	15.5	1.060
14	7.7	1.030	29	16	1.062
15	8.3	1.032	30	16.6	1.065

In using this table note that in passing from a higher to a lower
temperature divide the observed resistance by the number opposite
the degrees of difference of temperature, and in passing from lower to
higher multiply the same.

Example: A piece of cable is measured at 85° F. and has a resist-

ance of 100 ohms. The resistance per mile (9.5 ohms) is given at 75° F. The difference is 10° F. higher than the standard.

$$100 \div 1.021 = 97.94 \text{ ohms at } 75° \text{ F.}$$

and the length of the piece is $97.94 \div 9.5 = 10.31$ miles.

After laying the cable, in attempting to measure its resistance through the ground connections at each end the simplicity vanishes of measuring with the Wheatstone bridge and balancing until the galvanometer is at zero. It will be found that after making connections and before depressing the battery key that if we depress the short-circuit key a deflection will generally be noted. This is largely due to earth current (called E. C. in reference books). If it were steady it could easily be dealt with. Unfortunately it is not, and it is constantly varying in direction as well.

Two ways of measuring to eliminate earth-current effects are
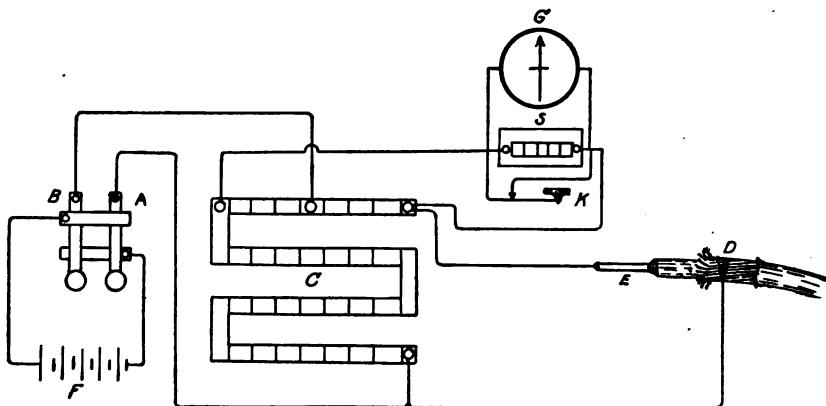
FIG. 22.

described in works on cable testing called respectively Quick Reversals and False Zero (see pp. 48 and 49, *Students' Guide to Submarine Cable Testing*, Fisher & Darby). A brief additional description of these may be useful.

Connections for measuring copper resistance are shown in fig. 22. $A B$ is the reversing key, C is the Wheatstone bridge, G is the galvanometer, S the universal shunt, K the short-circuit key, F the testing battery. The bridge is connected with the cable conductor E prepared as shown, and A and the bridge are connected to a brightened place on the cable armor wires for ground connections, as explained under capacity measurements. Of course, in this case, the distant end of conductor is connected with the armor wires or ground. As will be seen, by depressing B the copper (or carbon) end of the battery will remain connected with the ground, while the zinc goes to cable conductor through the bridge. Due to the fact that the "zinc current," as it is called, tends to clear away corrosion when measuring

to locate a fault, measurements made with it usually show lower resistances than when carbon or copper is put to line by depressing A. However, as little effect of this kind will be noted in sound cable with distant end well connected with ground as stated, we shall assume disturbances due only to earth currents in measuring.

The method by quick reversals will first be described. Depress B, wait a second or two, and depress K. Balance as rapidly as possible, noting resistance. Release B, then depress A and K, and again balance quickly. The mean of these resistances will give the one approximately correct, unless there is too great a difference between them, in which case the correction on page 46, Fisher & Darby, should be applied.

Balancing to false zero (F. Z.) is the usual method of providing for earth currents in measurements of conductor (copper) resistances of cable.

Before depressing A or B, if we depress the short-circuit key we shall generally note a deflection. This is due to the earth current. Suppose to be fairly steady, its direction and amount should be noted. If variable, its mean in the time usually occupied by balancing should be noted. This is the false-zero position to which we balance, instead of the true or instrumental zero we have heretofore considered. If the earth current or false zero is constantly varying, it should be noted just before and just after taking a measurement and the false-zero position taken as the mean. Several measurements should be made until several successive results are obtained which accord fairly well. A good measurement of the copper resistance of the sound cable, is an absolutely necessary preliminary to the location of faults when they occur.

The results of the foregoing tests may be tabulated as follows.

Cable tests.

Location of terminals.	Kind of cable.			Length, nautical miles.[a]	Copper resistance (ohms.)		Insulation resistance (megohms).		Capacity (microfarods).		Temperature (Fahrenheit).
	Deep sea.	Shore end.	Manufacturer, or other data.		Absolute.	Per nautical mile.	Absolute.	Per nautical mile.	Absolute.	Per nautical mile.	

Date of laying, repairing, or testing in storage ....
(If repair, data of lengths taken up or laid to be entered under appropriate columns.)
Remarks concerning tests (instruments used, etc.)...
....
General remarks on condition of cable...
....
Tests made by...................
....
....
....

----

[a] Nautical mile is 6,087 feet (Clark, Sabine, Bright).

LOCATION OF FAULTS IN SUBMARINE CABLES.

The application of the measurements just described in the location of faults may now be dealt with. The more complete exposition of the subject in the books of reference cited is recommended to those who desire to go into the matter more deeply.

Faults on cables are similar in nature to those on land lines. When the cable is completely ruptured faults may be described under the following headings of Class I:

Class I: First. The conductor is in contact with the metal sheathing, and is "dead grounded."

Second. The conductor is considerably exposed by much of the insulation at and near the end being broken away.

Third. When the end of the conductor is only partially exposed or deeply buried in mud and sand.

Fourth. When the insulating material is drawn well over the broken end of the conductor almost completely insulating it.

Class II: Conductor ruptured; insulation remaining intact.

Class III: Break or abrasion of the insulating material, causing either a high-resistance leak (escape), or one approximating to a "dead ground," depending upon the amount of exposure of the conductor.

The behavior of the fault under working conditions or test will usually determine to which class it belongs.

Rupture of the cable is attended, of course, with total cessation of signals from the distant end, and this usually occurs suddenly. The end of the conductor is generally left more or less exposed. If left much exposed, or grounded on the cable armor, the galvanometer will indicate a comparatively steady current when moderate battery power is applied. If the exposure is small, or the end is buried in mud, great fluctuations in the current will be produced, and greatly different when different ends of the battery are placed to line. If the conductor is well drawn back into the insulation, or the conductor is ruptured inside the insulating covering, of course nothing but the transitory current of charge and discharge will be observed.

Damage to the insulation, exposing more or less of the conductor, very frequently is first noted as a "leak," which becomes worse and worse, until communication is interrupted. Unless the damage is extensive, the reception of feeble signals from the distant station will disclose that the fault belongs to Class III, and that the cable is not ruptured.

In locating the first of Class I it is evident that it requires only the measurement of the copper resistance. This, divided by the resistance

37

per mile, will locate the fault. In No. 4 of Class I, and in Class II a measurement of capacity is required. This, divided by capacity per mile, gives the distance.

In all the others where partial exposure of the conductor is involved and only one end is available at the testing room, localization is difficult, owing to the polarization at the fault and its consequent change of resistance with different strengths and directions of current. When faults are minute, this polarization very rapidly changes resistances from a few ohms to thousands, and vice versa, with such rapidity as to require the greatest skill and judgment in testing. In general, by putting zinc to line, the generation of hydrogen and consequent cleansing from metallic salts at the fault tends to open it up. While
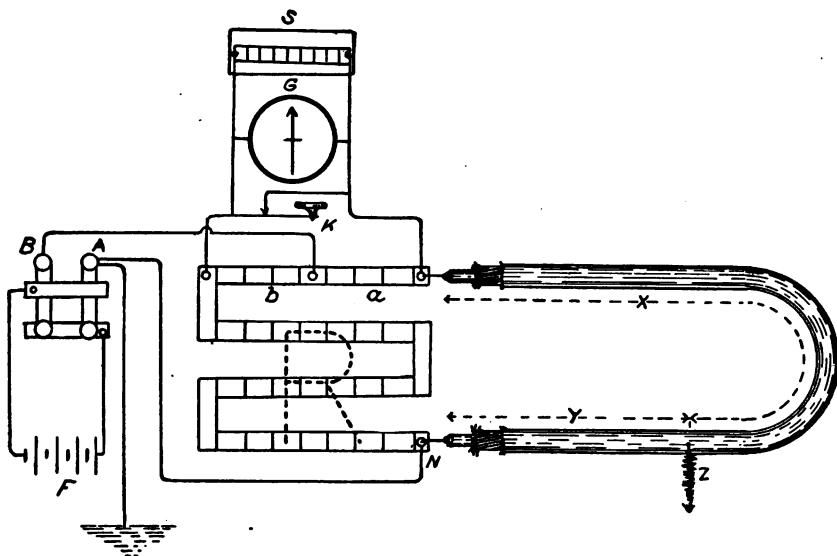
FIG. 23.

putting carbon or copper to line, by coating the fault with chloride of copper will cause the resistance to rise by sealing up the fault.

If the defect in insulation is small it is sometimes difficult to detect which pole causes the most rapid polarization.

When the cable is coiled in the tanks, where both ends are available, or when two cables have been laid between two points permitting their looping at the far end, or when the cable has multiple cores, one or more of which remain uninjured, faults in the insulation of a cable, where the conductor is not broken, may be quite accurately and easily located by the "loop test." This being the simplest method of locating these faults in cable, it will be dealt with first.

First measure the resistance of the loop with the two ends connected with Wheatstone Bridge, etc., as shown in fig. 22, page 35, connecting other end of loop to bridge in place of connecting bridge to D. Call this "L." Then change the connection, as shown in fig. 23.

It will be noted that the end with small resistance between it and the fault (Y) must be connected with (N), otherwise no balance can be obtained. When this is found to be the case, transpose the ends. When balance is obtained, call the values in balance arms a and b and amount unplugged in resistance R, as noted in diagram.

$$X = \frac{a(L+b)}{a+b} \quad Y = \frac{bL-aR}{a+b}$$

If $a=b$, $X = \frac{R+L}{2}$; $Y = \frac{L-R}{2}$.

When the break is of the second or third kind under Class I, it is usually indicated by more or less rapid polarization when the copper or carbon pole is put to line—that is, by a rise of resistance. The fact that it is a break is indicated by the cessation of even feeble sig-
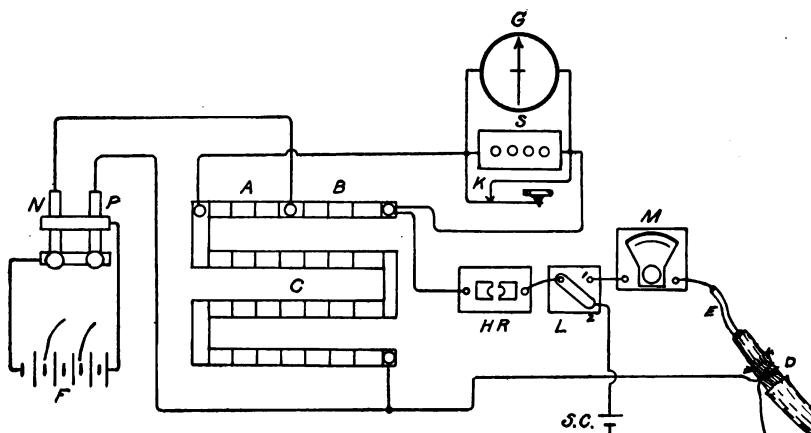
FIG. 24. — A, B, balance arms of bridge; C, standard resistances of bridge; D, ground connection (armor wires of cable); E, core of cable; F, testing battery; G, galvanometer; HR, high resistance (100,000 ohms); K, short-circuit key; L, two-point switch; M, Weston milli-ammeter; N, P, reversing key; $S. C.$, standard cell.

nals from the distant station. Sudden variations or jumps of resistance when the battery is applied indicates that the conductor is only partially exposed, or that it is deeply buried in mud or sand, thus preventing free escape of the gases liberated by electrolysis.

One of the late successful methods of dealing with breaks where the exposure is sufficient to not produce too great irregularities is Schaefer's method. This is described at length in Young's book, *Electrical Testing for Telegraph Engineers.*

The apparatus required in addition to the Wheatstone Bridge, reversing key, short-circuit key, galvanometer, shunt, and battery is the 100,000 ohms resistance (used in measurements of insulation resistance), a low resistance type milli-ammeter, like the Weston, and one or two cells of known electromotive force.

Connections are to be made as shown in fig. 24.

The first operation is to use the galvanometer as a delicate volt-meter, and with it to get some scale deflection corresponding to the known voltage of *S. C.* Unplug the 100,000 ohms in *HR.* Put lever of switch *L* on button 2, adjust the shunt *S* so when *K* is depressed a good readable deflection is produced. Plugs may be put in or removed from *B* for further adjustment if desired, *B* acting as an extra shunt in this case.

Suppose the deflection produced$=d$, and that the *EMF* of the standard cell or cells is *E.* The deflection being proportional to *EMF* the "divisions per volt" $D=\dfrac{d}{E}$. This constant is recorded together with the exact state of the shunt and the resistance in *A*, *B*, and *C.*

With the same adjustment of shunt, galvanometer, and resistance move lever of *L* from *1* to *2* and observe deflection due to earth current (*e*). If carbon or copper of *SC* was toward *L*, and earth current (*e*) deflection is in the same direction as *d*, its direction is the same as if testing-battery zinc were to line, and its apparent resistance effects on the reading will be additive and vice versa.

If this deflection is d', $e=\dfrac{d'}{D}$, then proceed promptly to measure the resistance. Put plugs in *HR* measure with zinc to line (to true zero, not false zero), noting resistance in *A*, *B*, and *R* and the reading of the milli-ammeter (*M*) at the time balance is obtained. Repeat this measurement, using in this case such amount of measuring battery as will give ratios of currents through milli-ammeter that are between 1 : 2 and 1 : 3. Always ground the cable between each set of observations for at least one minute to do away with polarization due to the testing current. Continue taking these sets of readings with two strengths of current, as noted above, until the similarity of successive sets will show a fair degree of constancy in *e* and the other conditions.

Suppose a set of observations gives the values of the resistances *R* and *R'*, and the corresponding milli-ammeter readings *nc* and *c.* Then Schaefer's formula gives as the true value of conductor resistance to the break:

$$X=R'-(R'-R)K'\mp\left[\left(\frac{e}{c}-\frac{c}{nc}\right)K'-\frac{e}{c}\right]$$

The term in brackets represents the earth-current correction to be applied. If the earth current is with the testing current, as shown by galvanometer deflections being in the same direction, it should be recorded $+$, and $-$ when in opposite direction. It is to be remembered that the order $\mp$ in formula corresponds to the order $\pm$ in earth-current readings.

The subjoined table gives the values of K' corresponding to the ratios of current strength nc and c in the set of observations:

Ratios nc to c.	K'.	Ratios nc to c.	K'.
1.1	14.140	3.4	1.640
1.2	7.644	3.5	1.617
1.3	5.475	3.6	1.595
1.4	4.385	3.7	1.576
1.5	3.732	3.8	1.558
1.6	3.296	3.9	1.541
1.7	2.985	4.0	1.525
1.8	2.749	4.1	1.510
1.9	2.566	4.2	1.496
2.0	2.420	4.3	1.483
2.1	2.299	4.4	1.470
2.2	2.199	4.5	1.459
2.3	2.114	5.0	1.408
2.4	2.040	5.5	1.369
2.5	1.977	6.0	1.337
2.6	1.921	6.5	1.310
2.7	1.871	7.0	1.289
2.8	1.828	7.5	1.269
2.9	1.789	8.0	1.253
3.0	1.753	8.5	1.239
3.1	1.721	9.0	1.226
3.2	1.692	9.5	1.215
3.3	1.665	10.0	1.205

As an example of the foregoing, the following is given of their measurements taken with each of the current strengths:

Milli-amperes through break.

Earth-current reading $e = .373$ volt.

nc 25.0 }Ratio
c 9.75} 2.56

K'{R 938.5   937.5   937.7
1.96{R' 1034.5 1033.5 1028.0
1.96 ×   96.0   96.0   90.3
         188.0   188.0   177.0
         846.5   845.5   851.0
         7.7   7.7   7.7
         854.2   853.2   858.7

$$\frac{e}{c} = \frac{.373}{.00975} = 38.3$$

Mean 855.3 ohms.

$$\frac{e}{nc} = \frac{.373}{.025} = 14.9$$

$$\left(\frac{e}{c} - \frac{e}{nc}\right) = 23.4 \times K' = 46.0$$

$$\frac{e}{c} = \underline{38.3}$$

Earth-current correction = 7.7 ohms.

The mean of several sets should be taken.

The best conditions for making the tests are stated to be:

First. Use as large currents as the bridge, length of cable, and size of break will permit. It should be remarked that irregularity of current would indicate a small area of exposed conductor and consequently too much current.

Second. Make the ratios of currents nc and c not less than 1:2 nor more than 1:3. For breaks at moderate distances Schaefer's system is very accurate and rapid.

In general, the location of faults of Class III presents the greatest difficulty. Of course, if a second and sound cable or another sound core in same cable joining the two places is available, the distant ends are looped, and the reliable "loop test" may be used.

And when the exposure of the conductor is considerable, making the fault resistance so low that none or barely perceptible signals can be got from the distant station, the Schaefer "break test" (pp. 40–42) may be applied, the distant end being insulated.

No other very satisfactory method exists of locating leaks (escapes) on cables when facilities exist for taking observations at one end only. Where the fault resistance is 200 ohms or less the Blavier test may be used. This has already been briefly referred to under land-line testing. The success attained in cable work depends greatly on the skill and judgment of the operator. The plain Blavier test will again be briefly described and the necessary corrections for these measurements will then be taken up.
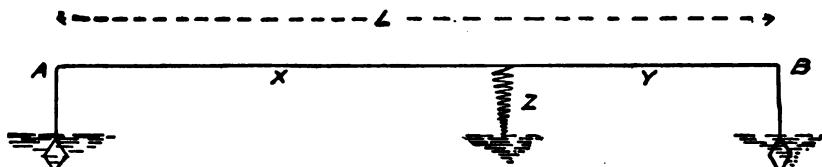
FIG. 25.

The copper resistance (L) of the cable when sound must be known. A leak occurs at some point, Z, and measurements are made from A— first, with end B connected with earth, and, second, with B insulated. Take these measurements with zinc to line, and preferably by false zero observations. Call the resistances obtained at A, N, and M ohms, respectively. The resistance X to the fault from A would then be $N - \sqrt{(L-N)(M-N)}$. This is supposing that the resistance of the fault Z remained the same in each measurement. Unfortunately, it does not, owing to its resistance changing with the greater current flowing through it when B is insulated.

The arrangement made at A to make requisite changes in the two cases to cause equal currents to flow through Z is shown in fig. 26.

The usual reversing key, bridge, etc., is used, the connections being as shown. G' and S' represent a galvanometer and shunt, their combined resistance being very small. A Weston milliammeter may be used instead. A resistance (D), which may be varied as required, is inserted in the battery circuit.

The resistances M and N are now measured to get the "plain Blavier" test and the values of M, N, and X obtained, no resistance being unplugged in D, and no notice being taken of the readings of G'.

The current to be used in subsequent measurement with distant end insulated is obtained as follows:

Let C = deflection of G' or milliammeter corresponding to N. Multiplying C by the ratio $\dfrac{N-X}{M-X}$ we get the proper deflection to be used in measuring M. In this measurement D is accordingly unplugged until the proper deflection appears. Take another pair of measurements, using the correct ratio of currents thus obtained, and from these work out another and more accurate ratio of currents. Continuing this process concordant results for several pairs should be obtained. The mean of these should give the correct result.
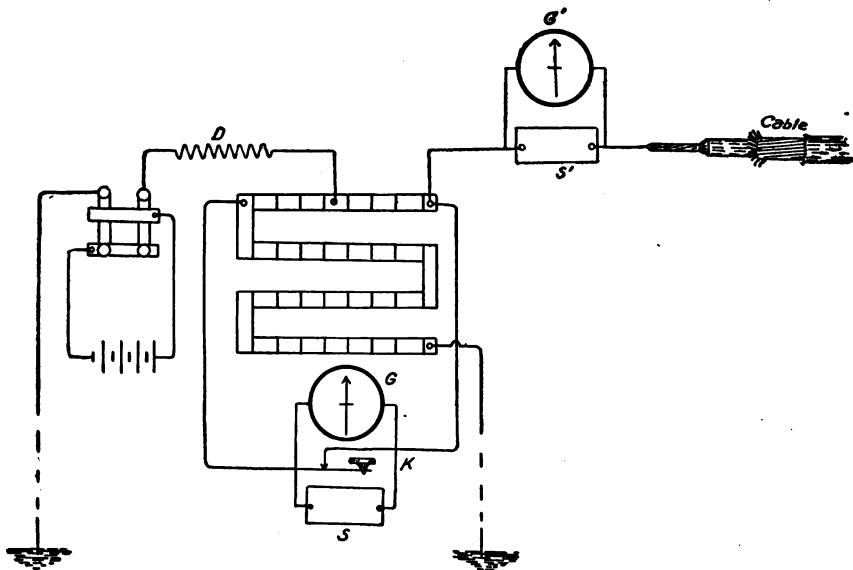
FIG. 26.

Example: A cable when sound had a resistance of 3,950 ohms. The "plain Blavier" gave on the faulty cable: M=3,200 ohms and N= 2,150 ohms: zinc always to line:

$$X = 2{,}150 - \sqrt{(3{,}950 - 2{,}150)\,(3{,}200 - 2{,}150)} = 775 \text{ ohms.}$$

Current ratio: $C\dfrac{2{,}150-775}{3{,}200-775} = C\dfrac{5}{9}$

The measurement of N was then made again, noting the galvanometer. This time N was found to be 1,830 ohms, and the deflection of G' noted. This was found to be 200 divisions.

Then M was measured and D unplugged until $\frac{5}{9}$ of 200=110 is indicated on G'. The lowest reading obtained was 2,170.

$$X' = 1830 - \sqrt{(3{,}950 - 1{,}830)\,(2{,}170 - 1{,}830)} = 981 \text{ ohms.}$$

In the next measurement correct ratio is

$$C\frac{1{,}830-981}{2{,}170-981} = C\frac{5}{7} \text{ nearly.}$$

These measurements are several times repeated and the mean of these corrected results taken.[a]

If first test should show N greater than M it would make solution impossible, in which case make a rough guess at the position of the fault and begin working corrections from that as a starting point.

Ayrton's modification of Blavier's test may be used when the copper resistance (L) is not known with sufficient exactness. In this in addition to M and N a third measurement (P) is made with distant end grounded through a known resistance (g) of several hundred ohms (two relays, for instance).

The resistance to the fault is given by the formula:

$$x = M - \sqrt{\frac{(M-P)(M-N)g}{P-N}}$$

$$z = M - x$$

$$y = \frac{Nz - Xz}{x + z - N}$$

To keep the current through the fault the same in each measurement, the EMF of the batteries in the three cases should be arranged, after the preliminary test, as follows:

$$E_1 : E_2 : E_3 :: \left(x + z + \frac{xz}{L-x}\right) : (x+z) : \left(x + z + \frac{xz}{L-x+g}\right).$$

Corresponding to N, M, and P, respectively, L in this case being the roughly approximate resistance of the line.

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[a] See Young's *Electrical Testing for Telegraph Engineers,* pages 159 et seq.

DESCRIPTION OF FISHER CABLE TESTING SET, NO. 2.

This set was originally designed by Mr. H. W. Fisher. It is intended for work where a strictly portable set is required.

As it will frequently be used for hunting trouble, a special arrangement of the bridge has been adopted so as to greatly facilitate Murray & Varley loop tests for faults. Mr. Fisher has also introduced a method new to portable cable-testing sets for locating breaks in cables where the conductor has parted; and, in addition to the usual one, a
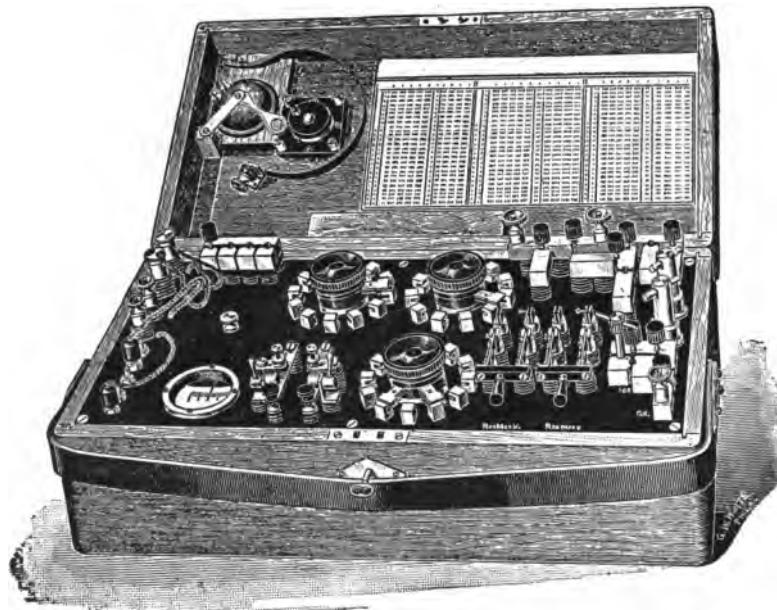
Fig 27.

new method for measuring capacity in which no galvanometer is required, a telephone being used in place of it.

The parts are mounted on corrugated hard-rubber pillars, which extend above and below the base.

This arrangement gives a very good insulation, and one that will be found entirely satisfactory, except under the most trying condition of moisture. The changes from one test to another are accomplished very easily and without the use of inconvenient flexible cords. They

are effected by double-throw switches which are plainly marked so that it is not necessary to memorize a complicated scheme of connections.

The standard of capacity has a single value of $\frac{3}{10}$ microfarad.

The standard high resistance is 100,000 ohms, and is also a single value, not subdivided.

In the Wheatstone bridge a marked variation from the usual commercial type has been made. The change is introduced to facilitate measurements for the location of faults. It is an extension of the Kelvin-Varley slides, and since it may not be generally known the following description is given. It is a form of Wheatstone's bridge resembling those having a slide wire in which the values of the rheostat are fixed and the two arms of the bridge are varied until a balance is effected. The arrangement is represented in diagram in fig. 28.

The points marked G and B are the points of attachment for the galvanometer and battery. At R are represented the four coils of
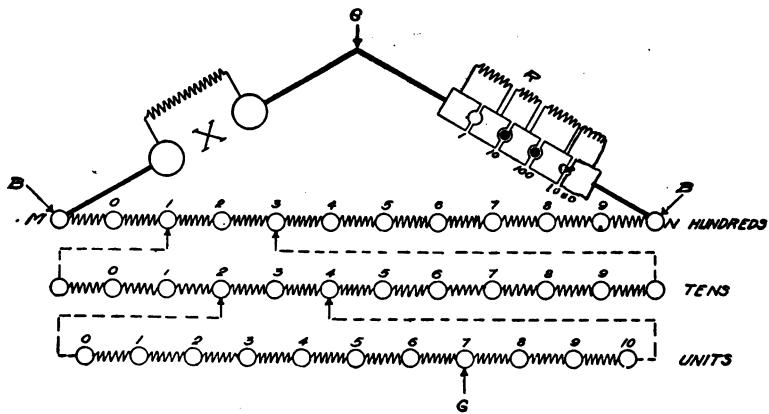
Fig. 28.

the rheostat, any one of which may be used, and at X the unknown resistance. Between M and N are eleven coils of equal value which form the bridge wire. There is a contact point between each coil and the one next to it. The other coils shown in the series marked "Tens" and "Units" are used to subdivide the coils of the bridge. They constitute what may be called an electrical vernier, by means of which the bridge wire is subdivided to thousandths of its total value. The two arrows in contact with the points marked 1 and 3 in the "Hundreds" row and with the 2 and 4 in the "Tens" row represent contact arms which can be moved along to make contact at any of the contact points, but are always at the same distance apart so that they have two coils between them. They are connected to the ends of the row of coils below them so that these two coils are shunted with the entire row of coils below. Consider now the result of this shunting in the case of the "Tens" and "Units" coils. The tens are, for

example, eleven coils of 80 ohms each. The units are ten coils of 16 ohms each. The two 80-ohm coils between the points *2* and *4* are shunted with the ten 16-ohm coils; 160 ohms is shunted with 160 ohms, and the resistance between the points *2* and *4* becomes 80 instead of 160 ohms. There are in the "Tens" series, for any position of the double arms, actually ten resistances of 80 ohms each. The point of galvanometer contact may be placed at any position in the "Units" series, thus subdividing the shunted coils in the "Tens" series to tenths. The coils in the "Hundreds" series are 400 ohms each, and are subdivided in the same way by those in the "Tens" series. An example will make the use of the bridge clear. Assume that a balance is obtained with 100 unplugged in the rheostat and the contacts in the position shown. The bridge reading is then 237. Call this value A. Then

$$X: R :: A: 1000-A, \text{ and } X = R \frac{A}{1000-A} = 100 \tfrac{237}{763} = 31.06$$

The calculation of the fraction $\tfrac{237}{763}$ would take considerable time, and might lead to errors. To overcome the necessity for this we furnish, conveniently fastened into the lid of each set, a table giving the values of $\frac{A}{1000-A}$ for all values of A between 0 and 1000. Reference to the table shows $\frac{A}{1000-A} = .3106$ for $A = 237$. We have, consequently, simply to multiply the value taken from the table by the resistance unplugged in the rheostat to determine the value of X. From this it will be seen the Wheatstone bridge measurements may be made and calculated very rapidly.

In the actual construction the coils are arranged in three dials. The contact arms and points are constructed so as to insure good contacts.

From the plan fig. 29 and the diagram fig. 30 the arrangement and connection of the different instruments making up the set will be evident. Complete information in regard to the measurements for which the set may be used can be obtained from the following directions:

MEASUREMENTS OF ELECTROSTATIC CAPACITY.

In making tests of this nature a reflecting galvanometer should be employed, because the galvanometer of the testing set is not sufficiently accurate, nor has it a long enough scale to give good results. A reflecting galvanometer should therefore be connected to the posts marked *Ga*. A few cells of battery can be connected to the posts *Ba* by means of the flexible cords which come out through the hard rubber opposite said posts. If a larger battery is required the flexible cords should be disconnected from the battery of the set and connection from any other battery made to the posts marked *Ba*. Connect the two leading wires running from the conductor of the cable and
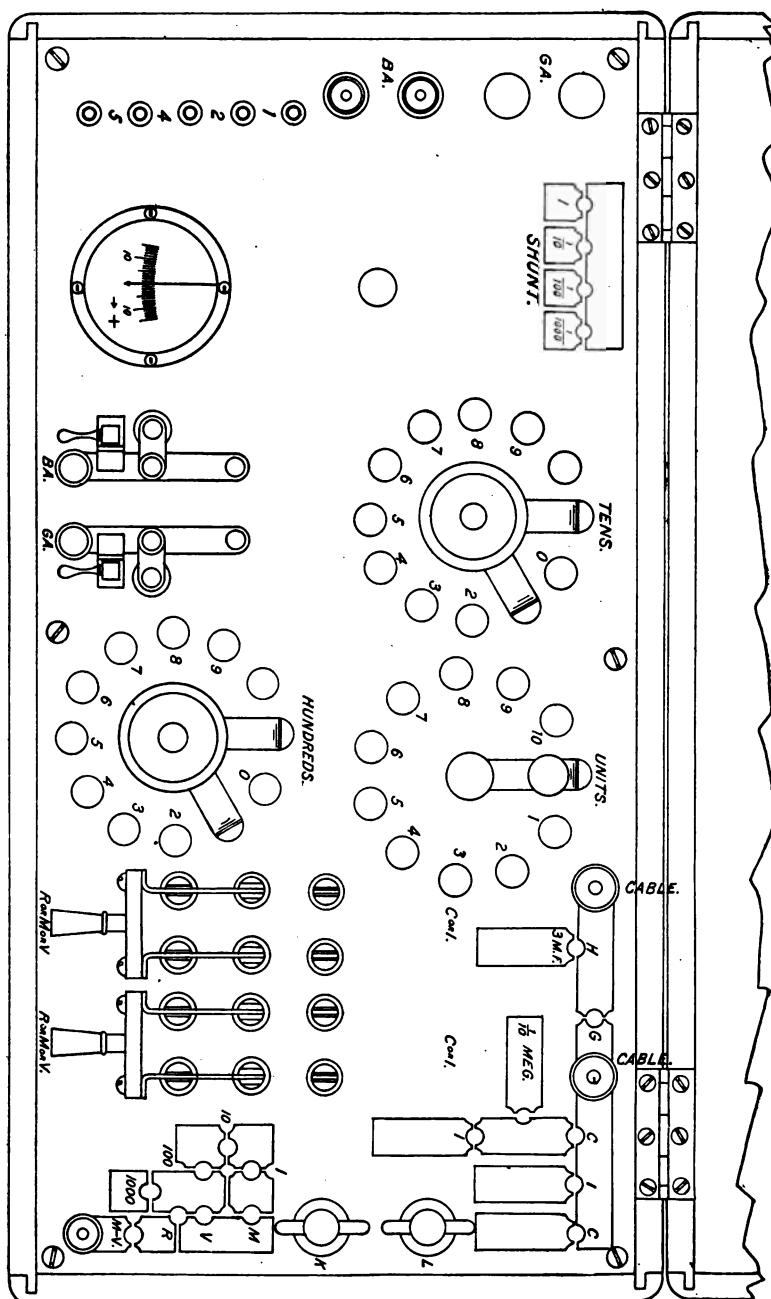
FIG. 29.

from the ground to "cable posts" and insert a plug in the hole marked 1 of the shunt. Place the handles of the two double-throw switches in the direction of the letters marked C or I. In this test the key marked Ba serves to close the battery circuit, the contact point being held in place by the finger or by pressing down the cam lever at the side of the key. The key marked Ga serves as a short-circuit key in this test, and the short circuit is removed from the galvanometer by pressing the key down or by the use of the cam lever. Insert two plugs in the holes marked C, and be sure that no plugs are inserted in the holes marked I nor in the hole marked G.
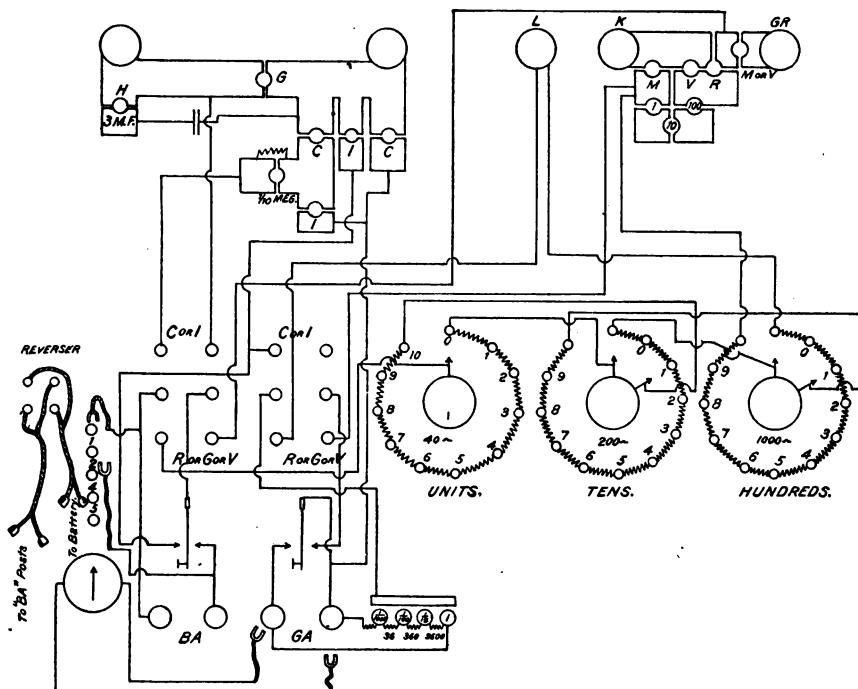
Fig. 30.—Plan of connections.

The test can now be made in the ordinary manner, as follows:

Press down the key marked Ba for about ten seconds, or whatever the required time of charging may be, and the instant before releasing it press down the key marked Ga to remove the short circuit from the galvanometer. Then the Ba key can be released and the discharge deflection of the galvanometer read. If it is too small, apply more battery until a sufficiently large deflection is obtained, which record. Next disconnect the cable lead wires from the conductor and in like manner measure the discharge deflection due to the leading wires. Then, without in any way changing or disconnecting the leading wires, insert a plug at H to connect the 0.3 microfarad condenser across the

cable posts, and in like manner read the discharge deflection of the condenser. It is not necessary to jam the plug too tightly in place. because in doing so the hard-rubber posts may be strained.

To obtain the true discharge deflection of cable and condenser, subtract the discharge deflection due to the leading wires from the observed discharge deflection of cable and condenser. Then letting

c = amount of condenser capacity used = 0.3 microfarad in this case,
dd = the true discharge deflection due to the cable,
dd' = the true discharge deflection due to the condenser,
L = the length of the cable in feet.

$$\text{The absolute capacity of the cable} = \frac{d \times c}{d'} = \frac{d \times .3}{d'}$$

And

$$\text{The capacity per mile of cable} = \frac{d \times .3 \times 5280}{d' \times L}$$

In order to prevent the EMF of the battery from changing in case of a test being made when the leading wires were accidentally crossed or the cable grounded, the cable or condenser is normally charged through the $\frac{1}{10}$ megohm box, but, if desirable, said resistance can be cut out of circuit by inserting a plug in the hole marked $\frac{1}{10}$ megohm.

MEASUREMENTS OF ELECTROSTATIC CAPACITY BY MEANS OF A TELEPHONE AND CONTINUALLY REVERSED BATTERY CURRENT.

NOTE.—The battery reverser is placed on the main rubber plate, the battery connections being connected directly to it. When the same is not used, the arrow on the side should always be made to coincide with the arrow stamped on the main rubber plate.

Remove the flexible galvanometer wires from their posts marked Ga and connect a telephone to said posts, place the shunt plug at 1, place the handles of both double-throw double-pole switches in the direction of the letters R or M or V, insert two plugs in the holes marked M. Plugs must not be inserted at either V or R. It is immaterial whether or not plugs are inserted in the resistances 1, 10, or 100. The keys marked Ba and Ga must be held down in place by means of their cam levers. Connect the cable to the post marked K and the lead of the cable or ground to the post marked Gr, and also to one of the posts marked "Cable posts;" connect the other cable post to the post marked $L;$ remove all plugs from the holes marked C, I, and G. Insert a plug in the hole marked H. The test can now be made in the following manner:

Place the rotating switches marked "Tens" and "Units" at zero. Then rotate the battery-reversing switch fastened to the lid, and having placed the telephone to the ear rotate the dial switch marked "Hundreds" until a point is found where the noise in the telephone is least.

It is advisable to use a telephone with a head gear, so that the battery-reversing switch can be rotated with one hand and the dial switches operated with the other. The next step is to rotate the switch marked "Tens" until the position is found which gives the least sound in the telephone. In like manner the "Units" switch is rotated until no sound is observable, when the required point of balance is reached.

It must be remembered that when the point of least sound is reached with any dial that the balance point may be either smaller or larger than the figure indicated. For instance, suppose the least sound occurs at the point 3 of the switch marked "Hundreds" and that the sound gets louder when the switch marked "Tens" is rotated, it is conclusive that the balance is less than 300, and hence the point *2* of the "Hundreds" dial must be used. In like manner discrimination must be used between the "Tens" and "Units" switches. When a balance is obtained write down the reading in the order of "Hundreds," "Tens," and "Units."

Letting said reading $= A$,

Letting C = condenser capacity $= .3$ microfarad in this case,

Letting L = length of cable in feet,

The capacity of the cable $= \dfrac{A \times C}{1000 - A} = \dfrac{A \times .3 \text{ microfarad}}{1000 - A}$

The capacity per mile $= \dfrac{A}{1000 - A} \times \dfrac{.3 \times 5280}{L}$

The value of the term $\dfrac{A}{1000 - A}$ is found in the accompanying table opposite the value of A.

This method is quite sensitive and can be readily applied. The results are slightly lower than those obtained by the first method, because a cable, as a rule, electrifies rather more slowly than the condenser. The results by the second method will be more concordant when the time of charge by the first method is made equal to the time of one reversal by the second method or when the handle of the battery reverser is rotated very slowly by the second method.

MEASUREMENTS OF INSULATION RESISTANCE.

In making the measurements of insulation resistance a reflecting galvanometer can be used by connecting it to the post marked Ga and disconnecting the flexible leads adjacent thereto which run to the horizontal galvanometer, or when approximate tests have to be made the galvanometer of the set can be employed by connecting the above-mentioned flexible leads to the post marked Ga. In like manner an auxiliary battery can be connected to the post marked Ba, or the battery of the testing set can be employed by connecting the number of cells required to the flexible cords adjacent to Ba. After making the

connections indicated above the handles of the two double-pole double-throw switches are placed in the direction of the letters C or I. The two leading wires from the cable conductor and from the ground are connected to "cable posts." Insert plugs into the two holes marked I and see that no plugs are inserted in the holes marked C, G, and H. The test can now be made in the ordinary manner, as follows:

Close the battery circuit by means of the key Ba and its accompanying holding-down cam. Shortly before the period of electrification, which is generally one minute, has elapsed, press down the key marked Ga to remove the short circuit from the galvanometer, when the deflection can be read. Then disconnect the leading wires from the cable conductor and in like manner measure the deflection due to the leading wires, which must be subtracted from the observed deflection first read to give the true deflection due to the cable.

A shunt plug can generally be placed at I, but if the insulation is low the $\frac{1}{10}$ or $\frac{1}{100}$ shunt may have to be used, when the deflection must be multiplied by 10 or 100, respectively, to get the true deflection.

The insulation constant of galvanometer is next determined, as follows:

Remove the plug from the hole marked $\frac{1}{10}$ megohm and insert a plug at G. Use whatever shunt will give the best readable deflection, which we will call D'. Then the insulation constant of galvanometer $= \dfrac{D'}{10 \times \text{shunt used}} = G$.

Letting $D =$ the true deflection due to the cable,

Letting $L =$ the length of the cable in feet,

Then,

The absolute insulation resistance of the cable $= \dfrac{G}{D}$

and the insulation resistance per mile $= \dfrac{G \times L}{D \times 5280}$

It is best to make the regular insulation resistance test with the $\frac{1}{10}$ megohm in series, and this is done by removing the plug from the hole marked $\frac{1}{10}$ megohm. Where great accuracy is desired the $\frac{1}{10}$ megohm can be subtracted from the calculated absolute insulation resistance to get the true insulation resistance. This is advised, so that the battery can never be short circuited.

DETERMINATION OF ELECTRIC POLARITIES.

When the constant of galvanometer above mentioned is taken with the positive and negative sides of the battery connected to the corresponding positive and negative flexible cords, the corresponding polarities are found as marked at cable posts, and the galvanometer needle deflects toward the plus sign. To measure unknown polarities, therefore, such as those of electric street railroad currents on water

pipes or cables, connect the wires of the terminals whose polarity is desired to the posts marked *Ba*, and making the connections to determine the constant of galvanometer as explained under "Measurements of insulation resistance," the plus terminal can be immediately determined. In like manner voltages can be measured by first calibrating the galvanometer by means of a cell of known *EMF*.

MEASUREMENTS OF CONDUCTOR RESISTANCE.

Place the handles of the two double-pole double-throw switches in the direction *R* or *M* or *V*, insert a plug in the hole marked *R*, and at the same time see that no plugs are in the holes marked *M* or *V*. It will be noted that there are four resistances, viz, 1, 10, 100, and 1,000 ohms. Any one of these can be used in the test by removing its corresponding plug and inserting plugs in the other three holes. Before commencing the test a resistance near to the probable resistance to be measured should be left unplugged. For instance, if 5 ohms or less have to be measured the 1 ohm resistance should be left unplugged. If the probable resistance to be measured lies between 5 and 50 ohms the 10 ohms resistance should be left unplugged; if the resistance to be measured is over 50 ohms the 100 ohms resistance should be left unplugged.

Connect in the resistance to be measured to the posts *L* and *K*. By means of the flexible cords opposite the posts marked *Ba* connect a few cells of battery at first, and if necessary the whole 12 cells later. Connect the flexible cords opposite the posts marked *Ga* to said posts. For the commencement of the test the $\frac{1}{10}$ shunt can be used, and for the final adjustment the 1 shunt.

The test can now be made by first placing the arms of the "Tens" and "Units" dials at zero and moving the "Hundreds" dial to 5. Press down first the battery key and instantly thereafter the galvanometer key, and note the direction in which the galvanometer pointer moves. If the battery flexible cords have been connected as indicated by the corresponding plus and minus signs, a deflection of the galvanometer toward the plus sign indicates that the dial resistance must be increased, while if the deflection is in the opposite direction, the dial resistance must be decreased. With this information in mind an instant only is required to determine between which two sets of "Hundreds" the balance point lies. Having found this, place the pointer at the lowest of the two, and in like manner determine between which two sets of "Tens" the balance point lies, placing the switch at the lowest of these. The final balance can then be found by rotating the "Units" switch until a point is reached when there is no deflection of the galvanometer. With the "Tens" and "Hundreds" switches the reading is taken between the two contact arms, while with the "Units" switch the reading is taken at the segment with which the rotating arm is in contact.

Letting R = the unplugged resistance to the right of the double switches,

And,

Letting A = the reading of the dial switches arranged in the order of hundreds, tens, units,

the resistance to be measured $= \dfrac{A}{1000-A} \times R$ ohms.

The value of the term $\dfrac{A}{1000-A}$ can be found in the accompanying table when it is only necessary to multiply said value by the amount of resistance unplugged.

MURRAY LOOP METHOD OF LOCATING GROUNDED OR CROSSED WIRES.

This is the simplest method of locating grounds or crosses, and is applicable when the faulty and good wire are of the same size and length; hence it can be used to locate such faults in telephone and telegraph cables where all the conductors seldom become faulty before the method can be applied. It can also be used in the case of an electric cable where the outgoing and incoming cable are the same size and length, and where one of them is not faulty. To apply this method join the faulty and good conductor at the distant end of the cable and connect the faulty conductor to L and the good conductor to K. Place the two double-throw double-pole switches in the direction of R or M or V, insert plugs in the two holes marked M, and be sure that no plugs are in the two holes marked, respectively, V and R. The resistances 1, 10, and 100 can be either plugged or unplugged without affecting the test. Connect the ground, or in the case of a cross the wire crossed with the one used in the test, to the post marked Gr. The galvanometer and battery are connected in the same manner described under "Measurements of conductor resistance." The description there giving the operating of dial switches is exactly the same as must be followed in this case.

Letting A = the reading of the dials which gives a balance of the galvanometer,

L = the total length of the circuit = twice the length of the cable if the good and bad wires are in the same cable,

Then,

The distance to the fault from the post $L = \dfrac{A \times L}{1000}$

The check method can now be applied by connecting the faulty conductor to K and the good conductor to L.

Letting A' = The reading of the dials which gives a balance,

$1000 - A'$ should $= A$

and therefore,

$\dfrac{1000-A'}{1000} \times L$ the distance to the fault by the check method.

When dealing with faults of high resistance 50 or more cells of battery may have to be used. Said battery should be connected to the posts Ba and the corresponding flexible cords should be disconnected from the battery of the set.

VARLEY LOOP METHOD OF LOCATING GROUNDED OR CROSSED WIRES.

Join the faulty and good conductor at the distant end of the cable, and at the near end of the cable connect the former to the post marked L and the latter to the post marked K. Then measure the resistance of the circuit as described under "Measurements of conductor resistance."

Let r = said resistance.

Place the handles of the two double-throw double-pole switches in the direction of R or M or V. Insert plugs in the two holes marked V and see that no plugs are in the two holes marked, respectively, M, R. Join the faulty and good wires at the distant end of the cable and connect the former to L and the latter to K, connect the ground or in the case of a cross, the wire crossed with the one used in the test, to the post marked Gr. Unplug the resistance marked 100 and plug the resistance marked 1 and 10, connect the battery and galvanometer and operate the dial switches in the same manner described under "Measurements of conductor resistance." If the balance can not readily be obtained it may be necessary to unplug the 10 ohm or perhaps the 1 ohm, the other two resistances must, of course, be plugged. The dial switches are now operated as described under "Measurements of conductor resistance" until a balance is obtained, when the reading is recorded.

Let R = the resistance unplugged in the rheostat,
Let r = the resistance of the faulty and good wires,
Let A = the reading of the dials which gives a balance of the galvanometer,

and,

Let $B = 1000 - A$,
Let a = the resistance to the fault from L,

then,

$$a = \frac{A \times (r + R)}{A + B} = \frac{A \times (r + R)}{1000}$$

CHECK METHOD.

Connect now the faulty wire to K and the good wire to L, and proceed in the same manner to find the new values A, B, R, and a, which for the check method we will call A', B', R', and a'.

The resistance to the fault from

$$K = a' = \frac{B' \times r - A' \times R'}{A' + B'} = \frac{B' \times r - A' \times R'}{1000}$$

Let b = the resistance of the faulty wire = one-half the resistance of the loop where good and bad wires are of the same size and are in one cable.

Let L = the length of cable.

Then,

$$\text{The distance to the fault by the first method} = \frac{a}{b} \times L.$$

$$\text{The distance to the fault by check method} = \frac{a'}{b} \times L.$$

METHOD OF LOCATING BROKEN WIRES BY MEANS OF A TELEPHONE AND CONTINUOUSLY REVERSING BATTERY CURRENT.

Remove the two pairs of flexible cords from the small box which is contained in the lid of the set, connect one pair to the battery and to two diagonal posts marked L 1 of the rotating reversing switch which is fastened to the inside of the lid. Connect the other pair of cords to the posts marked Ba and to the other two diagonal posts marked 2 of the reversing switch. Remove the flexible galvanometer wires from their posts marked Ga and connect a telephone to said posts. Place the shunt plug at 1, place the handles of both double-throw double-pole switches in the direction of the letters R or M or V, insert two plugs in the holes marked M. Plugs must not be inserted at either V or R. It is immaterial whether or not plugs are inserted in the resistance 1, 10, or 100. The keys marked Ba and Ga must be held down in place by means of their cam levers.

Connect the broken wire to the post marked K and a good wire in the same cable to the post marked L. If possible, all the other wires should be grounded to the lead of the cable as well as the section of the broken wire beyond the break. In a telephone cable it is best to use the mate of the faulty wire for the good wire mentioned above which is connected to the post L.

The test can now be made in the following manner:

Place the rotating switches marked "Tens" and "Units" at zero, then rotate the battery reversing switch which is fastened to the lid, and having placed the telephone to the ear rotate the dial switch marked "Hundreds" until a point is found where the noise in the telephone is least. It is advisable to use a telephone with a head gear, so that the battery reversing switch can be rotated with one hand and the dial switch operated with the other.

The next step is to rotate the switch marked "Tens" until a position is found which gives the least sound in the telephone. In like manner the "Units" switch is rotated until no sound is observable when the required point of balance is reached.

If the sound in the telephone is not loud enough when making the final adjustment with the "Units" switch it will be necessary to use

more cells of battery. The 12 cells of the testing set will, however, be enough for most purposes.

When a broken wire is to be located in a short section of cable it may be necessary to use 50 cells of battery or more, and this is done by connecting such a battery to one pair of the flexible cords running to the battery reversing switch and connecting the other cord from said reverser to the posts marked Ba. It must be remembered that when the point of least sound is reached with any dial that the balance point may be either smaller or larger than the figure indicated. For instance, suppose the least sound occurs at the point 3 of the switch marked "Hundreds," and that the sound gets louder when the switch marked "Tens" is rotated, it is conclusive that the balance is less than 300, and hence the point 2 of the "Hundreds" dial must be used. In like manner discrimination must be used between the "Tens" and "Units" switches. When a balance is obtained write down the reading in the order of "Hundreds," "Tens," and "Units."

Let said reading $= A$

Let B $= 1000 - A$

Let L $=$ the length of the cable

The distance to the break $= \dfrac{A}{B} \times L = \dfrac{A}{1000 - A} L.$

The value of the term $\dfrac{A}{1000 - A}$ can be found in the accompanying table.

This method can be very easily applied, and the results are very satisfactory. With this testing set, faults of this kind have been located within 2 or 3 feet in lengths of over 1,000 feet of cable.

The foregoing description and diagrams of the Fisher Cable Testing set are inserted by permission of Mr. J. G. Biddle, selling agent for the makers, Morris E. Leeds & Co.

USEFUL CONSTANTS AND FORMULÆ.

COPPER.

The specific gravity of copper wire, according to the best authorities, is about 8.899.

One cubic foot weighs about 550 pounds.

One cubic inch weighs 0.32 pound.

The ordinary breaking weight of copper wire is about 17 tons per square inch, varying, however, greatly according to the size and degree of hardness.

The weight per nautical mile of any copper wire is about $\frac{d^2}{55}$ pounds, d being the diameter in mils.

The weight per knot of a copper strand is about $\frac{d^2}{70.4}$ pounds.

The weight per statute mile of any copper wire is $\frac{d^2}{63}$ pounds. A mile of No. 16 wire weighs in practice from 63 to 66 pounds.

The diameter of any copper wire weighing w pounds per nautical mile is 7.4 $\sqrt{w}$ mils.

The diameter of any copper wire weighing w pounds per statute mile is 7.94 $\sqrt{w}$ mils.

The diameter of a copper strand weighing w pounds per nautical mile is about 8.4 $\sqrt{w}$ mils.

The resistance of a nautical mile of pure copper weighing 1 pound is, at 32° F., 1091.22 ohms; at 60° F., 1155.48 ohms; at 75° F., 1192.43 ohms.

The resistance per nautical mile of any pure copper wire or strand weighing w pounds, is $\frac{1192.45}{w}$ at 75° F.

The resistance per nautical mile of any pure copper wire d mils. in diameter is $\frac{65306}{d^2}$ ohms at 75° F.

The resistance per statute mile of any pure copper wire is $\frac{54892}{d^2}$ ohms at 60° F.

The resistance per nautical mile of any pure copper strand is $\frac{83964}{d^2}$ ohms at 75° F.

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The resistance, per knot, of a cable conductor is equal to 120,000 divided by the product of the percentage conductivity of the copper and its weight, per knot, in pounds.

The resistance of a statute mile of pure copper weighing 1 pound is 1002.4 ohms at 60° F. No. 16 copper wire of good quality has a resistance of about 19 ohms.

The resistance of a statute mile of pure copper weighing w pounds, is $\dfrac{1002.4}{w}$ ohms at 60° F.

The resistance of any pure copper wire L inches in length, weighing n grains $\dfrac{.001516 \times L^2}{n}$ ohms.

IRON.

The weight of any iron wire per nautical mile is $\dfrac{d^2}{62.6}$ pounds, d being its diameter in mils.

The weight of any iron wire per statute mile is $\dfrac{d^2}{72}$ pounds.

The diameter of any iron wire weighing w pounds per statute mile $=8.49 \sqrt{w}$ mils.

The diameter of any iron wire weighing w pounds per nautical mile $=7.91 \sqrt{w}$ mils.

The conductivity of ordinary galvanized iron wire averages about one-seventh that of pure copper.

The resistance per statute mile of a galvanized iron wire is about $\dfrac{360,000}{d^2}$ ohms, at 60° F.

CABLE TANKS.

To find the capacity of a circular tank—

Let r = radius of the eye.
R = radius of the tank.
d = diameter of the cable.
n = number of coils in one flake.

DISTANCES.

Let h be the height of tank or coil, then

Total length of cable $\dfrac{\pi h}{d^2} (R^2 - r^2)$

FIG. 31.

DISTANCE—SOUND.

Distance from shore—measurement by sound.—It sometimes happens that the distance of the ship from shore is required to be known, and a measurement by sound may be resorted to. For this purpose a gun is fired and the interval between the flash and the sound noted.

Let D=distance in knots;

T=temperature of air in degree Centigrade;

S=interval in seconds;

then

$$D=0.179\ S\sqrt{1+0.00374\ T}.$$

Example: A ship fired a cannon, and the sound was heard six and one-half seconds after the flash was seen. The temperature of the air was 15° C. Required, the distance (D) of the ship.

$$D=0.179\times 6\tfrac{1}{2}\sqrt{1+0.00374\times 15}=1.2\ \text{knots}.$$

FACTORY TESTING FOR THE ELECTRICAL PROPERTIES OF CABLE.

The Signal Corps specifications require the manufacturers to supply all instruments and facilities necessary for testing the cable. As these instruments are different at the different factories, a description of them will not be attempted. At the beginning of a series of tests at the factory, bridges, condensers and high resistances must be compared with standards to verify their accuracy.

The high-voltage test is first applied to the core. The breakdown test for the standard core, after twenty-four hours immersion in water, is the application of 5,000 volts alternating for five minutes. This test will discover any accidental impurities in the compound. While the specifications require the application of 5,000 volts for five minutes, if a breakdown occurs it will be disclosed almost instantly after the application of the high voltage. One lead from the transformer is connected with the copper of the core and the other lead immersed in the water in the tank. For the finished cable 1,000 volts are applied between the armor and the core for one minute. When the high voltage test is applied to lengths of armor cable of 50 miles, or more, it is, perhaps, better to use direct rather than alternating voltage, to avoid any possibility of resonance and the formation of stationary waves.

After the application of the breakdown test, the capacity, insulation, and copper resistances of each length of the core are determined in the order mentioned.

The capacity measurement is made by the charge method, as experience has demonstrated that, using a low voltage, the readings at charge and discharge are practically the same, as the effect of absorption is negligible. With some of the insulating compounds used the effect of the high-voltage test is to temporarily increase the capacity, and it will frequently happen that the first measurement may be higher than that required by the specifications, but if the cable is allowed to stand for twenty-four hours the capacity will probably drop to the limit prescribed by the specifications. When the first measured capacity is too high it should be remeasured after twenty-four hours. When the capacity of long lengths of cable is being tested, either Thompson's or Gott's method is preferable to using a shunted galvanometer. In measuring insulation resistance, especially in damp

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weather, care should be taken to thoroughly insulate the galvanometer, keys, and shunt box. The leakage from the galvanometer can be avoided by connecting the leveling screws together and then joining them to the insulated terminal of the battery key and by supporting the leveling screws on ebonite buttons.

In making the insulation measurement care should be taken to properly prepare the ends of the core, so as to avoid surface leakage. The ends should be freshly cut in conical form, allowing 2 or 3 inches of the copper core to project so that the lead may be attached, care being taken that the freshly cut surface is not touched by the fingers. It is a good plan to dry both ends with an alcohol lamp, taking care that the flame does not come close enough to injure the compound.

The copper resistance is measured by the usual bridge method.

In all cases, at the beginning of each series of tests, the leakage of the leads, their capacity, and resistance are determined.

The results of each day's work should be entered on the test sheet, and when the cable is finally completed, the data in respect to each core and finished cable length should be entered on the record sheet, a copy of which should be forwarded with each shipment, one retained in the office of the officer making the inspection, and the third copy furnished the Chief Signal Officer of the Army.

While the logarithmic method of computation is used in the illustrations which follow, it is much better to calculate the results with the Thatcher slide rule, which reads to four places of figures accurately, and by approximation to the fifth. One setting of this rule will serve for an entire series of calculations, and effects a very great saving of time.

In measuring capacity the method employed is the ordinary ballistic one, using a battery of but two or three volts. A deflection is obtained by charging a standard condenser, usually one-third of a microfarad, in series with a galvanometer, battery and key. The first throw of the galvanometer is noted, and the deflection for 1 microfarad calculated and entered on the test sheet. The cable is then substituted for the standard condenser, earthing one end and the battery, and the deflection read and noted.

In measuring insulation resistance the galvanometer constant is first obtained by connecting the high resistance, usually a megohm, in series with the battery of 100 volts, and galvanometer, which should be shunted with the $\frac{1}{1000}$ shunt, and observing the deflection, which is then corrected for the shunt and noted on the test sheet. The leakage of the leads, with the same voltage, is then obtained. The lead is then connected to the cable, the battery applied, the zinc pole to the cable, and the other side grounded. The deflection of the galvanometer is noted at the expiration of a minute, and this deflection is the one

from which the insulation resistance is calculated. It is well, however, to allow the battery to remain on for several minutes, noting the deflection at the end of each minute. This deflection should fall in a gradual and even manner. In the case of one of the compounds used, viz, that of the Safety Company, the deflection should halve itself, i. e., the insulation should double itself at the third and fifth minutes.

After the insulation resistance has been obtained, the bridge is used to measure the copper resistance of the core and the leads. The temperature of the tank is taken and noted. All measurements are made with the core or cable in the tank after it has been immersed for twenty-four hours, as the rubber compound will not attain its proper insulation at any given temperature until several hours after it has reached that temperature. There is always more or less uncertainty about the temperature, as the water in the different parts of the tank may not be at the same temperature; consequently care should be taken to get a uniform temperature throughout the tank. As there is less uncertainty with the core than with the finished cable, the copper resistances of the core reduced to the standard temperature may be, in case of doubt, taken as a base for calculating the test temperature of the finished cable.

The insulation resistance of rubber compound varies with the temperature, increasing as the temperature diminishes and decreasing as it rises. The temperature law of variation of the insulation resistance can be taken approximately as a simple logarithmic law. The insulation resistance, diminishing in equal ratio with an increase in the temperature, can be written in the form: $R = rC^t$, in which R is the resistance at the higher temperature, r the resistance at the lower temperature, t the difference in temperature in degrees Fahrenheit, and C a constant, depending on the nature of the insulation compound, which, for the Safety Company, can be assumed as 0.973, and for the Kerite 0.939. For reducing the insulation resistance at any observed temperature to that of the standard temperature, 60° F., it is necessary to have a factor to multiply the resistance of the observed temperature. The Okonite, Habirshaw, and Bishop companies have found that their compounds follow the logarithmic law sufficiently closely for all practical purposes. The coefficients of a number of compounds, according to this simple logarithmic law, are plotted in sheet 1 on logarithmic paper designed by Mr. Townsend Wolcott. The ordinates represent the temperature and are plotted arithmetically, while the abscissæ, the ratio of the insulation resistance at 60° F. to that at the temperature of observation are plotted logarithmically. The resistance at 60° F., being taken as unity, its logarithm, zero, is in the center of the paper, and the scale extends on the right to log. $\sqrt{10}$, and on the left to log. $\sqrt{.1}$.

The following table gives the factors for reducing the insulation resistance of the Okonite, Habirshaw, and Bishop companies' compounds to 60° F. according to the simple logarithmic law, these compounds doubling their insulation with a difference of temperature of 27° F.

Factors for reducing the insulation resistance of the Okonite, Habirshaw, and Bishop companies to 60° F.

Temper-ature.	K.	Log. K.	Temper-ature.	K. .	Log. K.
°F.			°F.		
50	0.773	9.888401	66	1.167	0.067071
51	.793	9.899629	67	1.197	.078094
52	.814	9.910802	68	1.228	.089198
53	.835	9.921906	69	1.260	.100371
54	.856	9.932929	70	1.293	.111599
55	.879	9.944240	71	1.326	.122544
56	.902	9.955460	72	1.361	.133858
57	.925	9.966576	73	1.396	.144885
58	.949	9.977572	74	1.433	.156246
59	.974	9.988853	75	1.470	.167317
60	1.000	0.000000	76	1.508	.178401
61	1.026	.011147	77	1.547	.189490
62	1.053	.022428	78	1.587	.200577
63	1.080	.033424	79	1.629	.211921
64	1.108	.044540	80	1.671	.222976
65	1.137	.055760			

As the result of careful observations of the temperature variation of the Safety and Kerite compounds, Mr. Wolcott gives the following formula:

$$\text{Log.}\left(\frac{R_t}{R_{60}}\right) = (.00802488 + .000044619t)\,(60 - t)$$

$$\text{Log.}\left(\frac{R_t}{R_{60}}\right) = (.00845964 + .000286604t)\,(60 - t)$$

in which R_t is the resistance at the temperature of observation and R_{60} is the resistance at 60° F. Calling the reciprocal of this ratio K, the following table has been calculated for the Safety and Kerite compounds:

Temperature coefficients for the reduction of insulation resistance to 60° F.

Temper-ature.	Safety.		Temper-ature.	Kerite.	
	K.	Log. K.		K.	Log. K.
°F.			°F.		
50	0.789	9.897441	50	0.591	9.772110
51	.807	9.907300	51	.619	9.792325
52	.826	9.917240	52	.650	9.813104
53	.845	9.927277	53	.683	9.834457
54	.865	9.937396	54	.718	9.856390
55	.886	9.947609	55	.756	9.878890
56	.907	9.957908	56	.797	9.901968
57	.929	9.968296	57	.823	9.925615
58	.952	9.978776	58	.891	9.949836
59	.975	9.989343	59	.943	9.974632
60	1.000	0.000000	60	1.000	0.000000
61	1.025	.010746	61	1.061	.025941
62	1.050	.021582	62	1.128	.052456
63	1.080	.033505	63	1.201	.079545
64	1.105	.043500	64	1.280	.107204
65	1.134	.054625	65	1.367	.135755
66	1.163	.065714	66	1.460	.164244
67	1.194	.077098	67	1.562	.193627
68	1.226	.088624	68	1.673	.223584
69	1.258	.099927	69	1.796	.254106
70	1.292	.111482	70	1.928	.285210
71	1.328	.123120	71	2.074	.316827
72	1.364	.134844	72	2.234	.349128
73	1.401	.146666	73	2.409	.381953
74	1.441	.158564	74	2.602	.415338
75	1.481	.170565	75	2.814	.449310
76	1.523	.182640	76	3.046	.483760
77	1.566	.194820	77	3.303	.518959
78	1.611	.207090	78	3.586	.554652
79	1.657	.219431	79	3.899	.590900
80	1.705	.231888	80	4.244	.627740

The resistance of copper increases with the increase of temperature. In order to reduce copper resistances at any temperature between 50° and 80° F. to 60° F., the following table has been calculated in which δ is the factor by which the resistance at the observed temperature should be multiplied to reduce it to 60° F.

Reduction of copper resistance to 60° F.

Temperature.	δ.	Log. δ.	Temperature.	δ.	Log. δ.
°F.			°F.		
50	1.022	.009451	66	0.9875	9.994519
51	1.019	.008174	67	.9847	9.993614
52	1.017	.007321	68	.9834	9.992707
53	1.015	.006466	69	.9813	9.991805
54	1.013	.005609	70	.9793	9.990903
55	1.011	.004751	71	.9773	9.990003
56	1.009	.003891	72	.9752	9.989107
57	1.007	.003029	73	.9732	9.988211
58	1.004	.001734	74	.9712	9.987317
59	1.002	.000868	75	.9692	9.986425
60	1.000	0.000000	76	.9672	9.985535
61	.9977	9.999081	77	.9653	9.984647
62	.9958	9.998165	78	.9633	9.983760
63	.9944	9.997551	79	.9613	9.982857
64	.9916	9.996338	80	.9594	9.981993
65	.9895	9.995428			

A general formula for reducing copper resistance at any observed temperature (T) to 60° is given by the following:

$$\delta = \frac{1.063}{1 + .00225\,(T - 32)}$$

The two following tables illustrate the manner in which the records of factory tests are kept, and the next is an example of a record sheet.

Record of cable tests for Signal Corps, U. S. Army.

[Date, July 5, 1901; place of test, Seymour, Conn.; manufacturer, W. R. Brixey; type of wire, core.]

Galvanometer constants [45,000 divisions through 2,064 megohms, 92,880 divisions through 1 megohm.
326 divisions through ⅓ microfarad. 978 divisions through 1 microfarad. Temperature, 75° F.
Leads {Leakage, 12 divisions. Conductor resistance, 1.64 ohms.
{Capacity, 5 divisions.

Reel or section No. —			Capacity.				Insulation.					Conductor resistance.			
Core length.		Length in feet.	Observed deflection.	Corrected deflection.	Total microfarads.	Microfarads per mile.	Observed deflection.	Corrected deflection.	Total insulation temperature of observation.	Total insulation at 60° F.	Insulation per mile at 60° F.	Total resistance.	Corrected for leads.	Total resistance at 60° F.	Resistance per mile at 60° F.
Miles.	No.														
1.000	116	5,280	296	291	0.298	0.298	197	185	502.1	1,426	1,426	11.37	9.73	9.43	9.43
1.004	117	5,300	292	287	.293	.292	172	160	580.5	1,649	1,666	11.34	9.70	9.40	9.36
1.002	118	5,290	295	290	.297	.296	124	112	829.4	2,356	2,361	11.26	9.62	9.32	9.30
.991	119	5,230	287	282	.288	.291	156	144	645	1,882	1,815	11.17	9.53	9.24	9.32
1.004	120	5,300	294	289	.296	.295	130	118	787.1	2,236	2,245	11.37	9.73	9.43	9.39
1.009	121	5,330	294	289	.296	.293	169	157	591.6	1,681	1,696	11.40	9.76	9.46	9.38
1.007	122	5,316	299	294	.301	.299	163	151	615.2	1,747	1,759	11.31	9.67	9.37	9.31
1.08	123	5,296	295	290	.297	.296	143	131	709.1	2,015	2,021	11.26	9.62	9.32	9.29
1.06	124	5,296	290	285	.291	.286	174	162	573.4	1,629	1,689	11.24	9.60	9.30	9.24
.977	125	5,160	290	285	.291	.298	128	116	800.7	2,275	2,223	11.15	9.51	9.22	9.44

Observations by Townsend Wolcott; calculations by T. W.

[Date, August 23, 1900; place of test, New York City; manufacturer, Safety Insulated Wire and Cable Company; type of wire, finished cable.]

Galvanometer constants {— divisions through —— megohms, 185,000 divisions through 1 megohm.
{256 divisions through 0.3 microfarad, 853 divisions through 1 microfarad. Temperature, 78° F.
Leads: Leakage, 29 divisions; conductor resistance, 1.38 ohms.

Reel or section No. 64.		Capacity.				Insulation.					Conductor resistance.			
Core length No.	Length in feet.	Observed deflection.	Corrected deflection.	Total microfarads.	Microfarads per mile.	Observed deflection.	Corrected deflection.	Total insulation temperature of observation.	Total insulation at 60° F.	Insulation per mile at 60° F.	Total resistance.	Corrected for leads.	Total resistance at 60° F.	Resistance per mile at 60° F.
Total {26765 feet. {5.107 miles.		1,800	1,800	2.100	0.413	970	941	196	510	1,621	94.5	93.12	87.66	17.16

Observations by S. R.; calculations by S. R.

Record sheet.

[Manufacturer, Safety Insulated Wire and Cable Company; type, deep-sea cable; loaded on U. S. Army Transport *Burnside.*]

Section number.	Length (miles).	Capacity.				Insulation.		Copper.			
		Core.		Cable.		Core, per mile.	Cable, per mile.	Core.		Cable.	
		Absolute.	Per mile.	Absolute.	Per mile.			Absolute.	Per mile.	Absolute.	Per mile.
85	5.138	1.988	0.387	1.775	0.345	1,613	1,073	90.26	17.58	90.32	17.58
86	5.097	1.944	.391	1.635	.321	1,421	1,150	89.31	17.52	89.60	17.58
87	5.082	1.775	.349	1.525	.300	1,269	1,119	86.36	17.57	88.92	17.50
88	5.125	2.063	.402	1.610	.314	1,350	778	86.99	17.55	88.47	17.26
89	4.855	1.750	.360	1.480	.305	1,409	1,108	85.12	17.13	85.46	17.61
90	4.853	1.750	.360	1.500	.309	1,416	1,077	85.05	17.52	83.95	17.30
91	4.848	1.795	.370	1.613	.333	1,416	1,122	85.39	18.01	83.95	17.20
92	4.841	1.964	.405	1.709	.352	1,637	1,312	84.95	17.53	84.25	17.37
93	4.877	1.807	.370	1.590	.326	1,487	1,232	85.24	17.47	85.31	17.49
94	5.133	1.889	.368	1.702	.331	1,510	1,099	89.97	17.53	89.32	17.40
95	5.138	2.115	.411	1.596	.311	1,610	1,043	90.15	17.54	88.46	17.30
96	5.097	1.863	.365	1.630	.320	1,261	1,306	89.11	17.48	87.98	17.26
97	5.112	2.012	.393	1.637	.320	1,454	1,039	90.34	17.68	91.34	17.87
98	5.098	1.978	.388	1.699	.333	1,699	1,306	89.50	17.56	88.40	17.35
99	5.107	1.884	.369	1.589	.311	1,267	852	89.14	17.46	90.32	17.68
100	5.138	2.172	.423	1.633	.318	1,358	1,205	90.22	17.56	89.40	17.40

The following computation illustrates the logarithmic method of calculating the data contained in record sheet of Safety Company, page 66.

CAPACITY.

Log. 1800 = 3.255273
Log. 853 = 2.930949

Absolute capacity, 2.110   .324324
Log. 5.107 = .708166

Capacity per mile, 0.413   1.616158

INSULATION RESISTANCE.

970 − 29 = 941
Log. 185000 = 5.267172
Log.   941 = 2.973590

Insulation at temperature of observation, 196   2.293582
Log. K   = .207090

Total insulation at 60° F., 510   2.501672
Log.   5.107 = .708166

Insulation resistance per mile, 1621   3.209838

COPPER RESISTANCE.

$$94.5-1.38=93.12$$
$$\text{Log. } 93.12 = 1.969043$$
$$\text{Log. } \delta \quad = 9.983760$$

Total resistance at 60° F.,   87.66   1.942803
Log. 5.107 = .708166

Resistance per mile at 60° F., 17.16   .234637

DATA FOR SAFETY INSULATED WIRE AND CABLE COMPANY'S COMPOUND.

Specific gravity of compound, 1.646.

Weight per cubic foot of compound, 103 pounds.

Capacity per mile, solid conductor $= \dfrac{.2063}{\log. D - \log. d}$

Capacity per knot, solid conductor $= \dfrac{.2329}{\log. D - \log. d}$

Capacity per mile, 7-stranded conductor $= \dfrac{.2063}{\log. D - \log. 2.27 \, \delta}$

Capacity per knot, 7-stranded conductor $= \dfrac{.2329}{\log. D - \log. 2.27 \, \delta}$

Insulation resistance per mile, solid conductor $= 1982$ (log. $D -$ log. d).

Insulation resistance per knot, solid conductor $= 1756$ (log. $D -$ log. d).

Insulation resistance per mile, 7-stranded conductor $= 1982$ (log. $D -$ log. 2.27 δ).

Insulation resistance per knot, 7-stranded conductor $= 1756$ (log. $D -$ log. 2.27 δ).

Weight per mile of compound, solid core $= 2956 \ (D^2 - d^2)$.

Weight per mile of compound, 7-stranded conductor $= 2956 \ (D^2 - 6.9 \ \delta^2)$.

$D =$ outside diameter of insulation.
$d =$ diameter of solid conductor.
$\delta =$ diameter of single strand.

DATA FOR KERITE.

Specific gravity of compound, 1.233.

Weight per cubic foot, 77 pounds.

Capacity per mile, solid conductor $= \dfrac{.1738}{\log. D - \log. d}$

Capacity per knot, solid conductor $= \dfrac{.1962}{\log. D - \log. d}$

Capacity per mile, 7-stranded conductor $=\dfrac{.1738}{\log. D - \log. 2.27\,\delta}$

Capacity per knot, 7-stranded conductor $=\dfrac{.1962}{\log. D - \log. 2.27\,\delta}$

Insulation resistance per mile, solid conductor $= 2147$ (log. $D -$ log. d).

Insulation resistance per knot, solid conductor $= 1602$ (log. $D -$ log. d).

Insulation resistance per mile, 7-stranded conductor $= 2147$ (log. $D -$ log. $2.27\,\delta$).

Insulation resistance per knot, 7-stranded conductor $= 1902$ (log. $D -$ log. $2.27\,\delta$).

Weight per mile of compound with solid core $= 2211$ $(D^2 - d^2)$.

Weight per mile of compound, 7-stranded conductor $= 2211$ $(D^2 - 6.9\,\delta^2)$.

$D =$ outside diameter of insulation.
$d =$ diameter of solid conductor.
$\delta =$ diameter of single strand.

Conversion tables.

Miles to knots.		Knots to miles.	
Miles.	Knots.	Knots.	Miles.
1	0.8674	1	1.1528
2	1.7348	2	2.3057
3	2.6023	3	3.4585
4	3.4697	4	4.6114
5	4.3371	5	5.7642
6	5.2045	6	6.9170
7	6.0719	7	8.0699
8	6.9394	8	9.2127
9	7.8068	9	10.3756

Miles to kilometers.		Kilometers to miles.	
Miles.	Kilometers.	Kilometers.	Miles.
1	1.60935	1	0.62137
2	3.21869	2	1.24274
3	4.82804	3	1.86411
4	6.43739	4	2.48548
5	8.04674	5	3.10685
6	9.65608	6	3.72822
7	11.26543	7	4.34959
8	12.87478	8	4.97096
9	14.48412	9	5.59233

100° .35

90°

80°

70°

60°

50°

40°

30°

20° .35